Bonneville Project
Columbia River
Bonneville
Multnomah County
Oregon

HAER No. OR-11

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Western Region
Department of the Interior
San Francisco, California 94102

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HISTORIC AMERICAN ENGINEERING RECORD

BONNEVILLE DAM

HAER No. OR-11

Location: Columbia River, 1 mile northeast of exit 40 of Interstate 84, 4 miles west of Cascade Locks, Oregon

U.S.G.S. 15 minute Bonneville Dam, Washington-Oregon, quadrangle, Universal Transverse Mercator coordinates: 10.582413.5055160

Date of Construction: 1933-1937

Engineer: C. I. Grimm, Chief Engineer

Builder: U.S. Army Corps of Engineers, Portland District

Present Owner: U.S. Army Corps of Engineers
319 S.W. Pine
Portland, Oregon 97208

Present Use: Dam, Navigation lock, Hydropower plant

Significance: Bonneville Dam was the first of eight federal lock and dam projects on the Columbia-Snake rivers. The dam's significance is derived from its unique engineering design, its contribution to the region's industrial development, the lock's role in transportation, the entrance landscaping and Colonial Revival style architecture of the administration and auditorium buildings, and the project's role as a major government undertaking in the 1930s to combat the Great Depression. Bonneville Dam was placed on the National Register of Historic Places as an historic district in 1986 and named a National Historic Landmark in 1987.

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PREFAGE

Engineering and building Bonneville Dam in the heart of the Columbia River Gorge proved a monumental task. The complex geology of the gorge combined with the great volume of the swift flowing Columbia to present many complex problems of site selection, proper construction techniques, and equipment design.

The project first received serious consideration in a 1931 Corps of Engineers' report to Congress. This study, the famous 308 Report, recommended constructing Bonneville Dam as part of a ten-dam effort to tap the enormous hydropower potential of the Columbia River. In addition, Bonneville and other proposed dams in the plan were to contain locks providing improved inland navigation. Depression-era politics drove the process leading to adoption of the Bonneville project by the Federal Government.

Conceived as a way to quickly employ large numbers of unemployed laborers and engineers while producing long-term hydropower and navigation benefits, Bonneville Dam amply lived up to the hopes and dreams of its promoters and designers. In the short term, Bonneville supplied essential power for the Portland-area shipyards and aluminum plants that helped win World War II. After the war, Bonneville's power spurred a period of regional economic growth and opportunity. With the completion of a second powerhouse and construction of a new navigation lock, the Bonneville project continues as a vital part of the Northwest economy. Today's Bonneville Dam, named for an Army captain who had explored and described the Columbia River Basin and its resources over 100 years before the dam's construction, stands as a testament to his vision of the region's future greatness.

This book is dedicated to the thousands of men and women whose energy and commitment built this engineering marvel in the "wilderness" of the Columbia River Gorge. Bonneville Dam has repaid the original investment of dollars, imagination, and toil many times over through the continuing benefits of jobs and affordable living for the people of the Pacific Northwest.

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INTRODUCTION

In 1987, the Secretary of the Interior designated the Bonneville Dam Historic District as a National Historic Landmark in recognition of its significance as one of the 20th century America's most important engineering sites. Encompassing a portion of the Columbia River, Bradford Island, the Bradford Slough, and a tract of land along the Oregon shoreline, the district included seven distinct components:

1) The Dam/Spillway
2) The First Powerhouse
3) The Original Navigation Lock
4) The Administration Building
5) The Auditorium Building
6) Landscaping
7) The Bonneville Fish Hatchery

<u>The Dam/Spillway</u> (OR-11-F-1, OR-11-F-18,19)

The dam/spillway structure comprised the key component of the Bonneville project because it raised the level of the Columbia River. Without the construction of the dam/spillway, there could be no hydroelectric power generation at the site. The dam/spillway extends across the main stem of the Columbia River and, when originally built, connected Bradford Island with the Washington State shoreline. Since construction of the Second Powerhouse on the Washington shore in the late 1970s, the dam/spillway has abutted onto the artificially created Cascade Island that is separated from the mainland by the channel built for the new powerhouse.

The dam/spillway, a massive concrete gravity dam with an overall length of 1,450 feet and maximum width of 180 feet, rose a maximum height of 197 feet above the deepest foundations. It was called a gravity dam because the hydrostatic pressure exerted by the water impounded in the reservoir was resisted solely by the force of gravity acting on the mass of concrete forming the structure. As an overflow dam, it allowed water to flow over the top of the structure during periods of heavy flooding. The downstream face of the dam formed a smooth, flat curve (technically known as an ogee curve) that permitted water to flow over it without major disturbance. Because flood waters "spill" over the dam on their way downstream, the structure was also referred to as a spillway. At the top of the spillway, eighteen vertical steel gates supported by concrete piers controlled water releases. Known as Stoney gates in honor of their 19th century British inventor, 12 of these gates were 50 feet high by 50 feet wide, and six of them were 60 feet high and 50 feet wide. As originally built, two 350-ton gantry cranes located on top of the dam raised and lowered the gates in order to control the amount of water flowing over the spillway. Recently, the Corps of Engineers altered most of the gates so that electric motors now control the raising and lowering operation. However, the gantry cranes remained in place to provide emergency service. At the lower end of the spillway structure, large, reinforced baffles were submerged at a depth of 15 feet below sea level. Although invisible during normal operating conditions, these baffles performed important work in dissipating the kinetic energy of the water passing over the dam/spillway. Repaired in the early 1950s, these baffles still retained their basic structural integrity.

At both ends of the dam/spillway, fish-lifts built into the original structure helped provide passage for anadromous fish swimming upstream to spawn. Fisheries experts designed these fish-lifts to physically lift a 20 feet by 30 feet rectangular chamber up the height of the spillway/dam and thus carry a load of fish over the barrier separating them from their spawning grounds. The fish-lifts operated as designed, but in practice proved an inefficient technology and were eventually abandoned. Although no longer used, the fish-lifts are still in place at the ends of the dam/spillway.

To pass spawning fish by the Bonneville Dam on their journey up the Columbia River, the Corps built an extensive complex of fish ladders. These fish ladders were large, sloping reinforced concrete channels that provided a passageway for fish to gradually ascend the height of water impounded by the dam. Fisheries experts designed three fish ladders for Bonneville. One was located at each end of the dam/spillway and one, at the north (Bradford Island) end of the original Powerhouse. Built along a roughly circular plan, the ladders extended 40 feet in width and were divided by 6 foot high concrete walls into discrete compartments 16 feet long. As water flowed down the ladders, these compartments formed a series of pools that the spawning fish gradually ascended. Originally, solid walls separated these compartments, forcing the fish to leap over them; later, engineers modified the walls by constructing small openings along their bottoms that allowed fish to swim under the wall if they chose. Along with the reinforced concrete fish ladders, the fish passage system included a bypass canal built south of the original Navigation Lock that allowed passage for newly-spawned fingerlings swimming downstream to the Pacific Ocean. This lengthy bypass canal extended behind the Auditorium Building and entered the Columbia River near the hatchery along Tanner Creek. The reinforced concrete fish ladders will not be affected by construction of the new navigation lock. However, the bypass canal lies directly in the path of the lock's right-of-way, and it will have to be reconstructed along a new alignment.

Two reinforced concrete control towers were located at each end of the dam/spillway. The towers at the downstream edge of the structure contained elevators descending into the interior of the dam/spillway. These elevators provided access to two tunnel-inspection galleries that extend the length of the dam/spillway at a depth over 30 feet below sea level. During World War II, small hexagonal-shaped, reinforced concrete guard houses were built at both ends of the dam/spillway. These structures had slits, allowing guards to fire guns at potential saboteurs or terrorists. Although no longer used, several guard houses presently are stored at the project.

<u>The First Powerhouse</u> (OR-11-E-98)

The First Powerhouse extended across the Bradford Slough (a channel of the Columbia River) between the Oregon shoreline and Bradford Island. The original powerhouse, a reinforced concrete structure, had a width of 190 feet and a total length of 1,027 feet. Built in a massive unadorned style, the structure featured a simple crenellated cornice extending along the length of the structure. The windows for the main generator room contained large expanses of framed glass that extend from the floor level of the generator room to slightly below the cornice line. The powerhouse's deepest foundations lay 93 feet below sea level, and the structure rose a maximum height of 190 feet above bedrock. All levels within the powerhouse reflected their elevation, given in feet, above or below sealevel. The powerhouse contained ten turbine/generator units within the main generator room that extended the entire length of the structure (level +55). A gallery at level +82 overlooked the main turbine room. The two turbine/generator units closest to the Oregon shore became operational first and had rated capacities of 66,000 horsepower and 43,200 kilowatts. The remaining eight units each have rated capacities of 74,000 horsepower and 54,000 kilowatts. In total, the powerhouse had a capacity of 518,400 kilowatts.

Kaplan turbines with adjustable blade, propeller-type runners powered all units. These turbines, manufactured by the S. Morgan Smith Company, automatically adjusted themselves to take best advantage of the waterflow and head (or water pressure) acting on the turbines at any given time. Each turbine weighed approximately 900 tons, exclusive of the generators; the runners had a diameter of 23 feet, 4 inches while the shafts had a diameter of 39.5 inches. The adjustable features of the Kaplan design were ideally suited to the variable hydraulic conditions on the Lower Columbia River. Waterflow from the upstream forebay passed through intake openings 65 feet high by 62 feet wide before reaching the scroll casings surrounding each turbine. Under full load, each turbine required 13,000 cubic feet of water per second (cfs). Twenty adjustable wicket gates controlled flow into the turbines and also limited water turbulence. The effect of turbulence on water discharging from the turbines was minimized by draft tubes (level -23) with a maximum diameter of 23 feet that carried the flow to the downstream afterbay channel.

The electric generators, manufactured by the Ceneral Electric Company, were vertical shaft units that produced 60 cycle, three-phase current at a pressure of 13,800 volts. Direct current exciters used to energize the electromagnets in the main generators sat directly on top of the turbine/generator units. The current flowed to large transformer units located in isolated service bays (level +90) at the upstream face of the powerhouse; transformers raised current voltage to either 66,000 volts or 110,000 volts before being fed into the Bonneville Power Administration power grid. Switching equipment located on top (level +125) of the powerhouse controlled transmission into the power grid. Operation of the entire powerhouse took place from a control room (level +77) overlooking the south (Oregon shore) end of the main generator room. The control room was recently automated, but most of the original equipment used to govern the operation of the turbines, generators, transformers, and switching equipment remained in place, serving as backup for the new equipment.

Other equipment in the powerhouse included a 300 ton crane running the length of the main generator room used to lift various components of the turbine/generator units during repair and maintenance operations. A large work area at level +55 on the north (Bradford Island) end of the generator room provided space for working on components moved there via the overhead crane. Two gantry cranes ran along the upstream face of the powerhouse (level +90) to raise and lower vertical gates controlling flow into the turbine forebays. A single gantry crane running along the downstream face of the powerhouse controlled vertical gates that closed off the end of the draft tubes. The powerhouse also contained numerous service galleries that extended the length of the structure and housed equipment related to the operation of the turbine/generators, transformers, and switching equipment. For example, level +77 contained the bus cell gallery and oil and water pipe gallery; level +65 housed the oil circuit breaker gallery; level +37 held the station service generator and transformers, actuator tanks, cooler pumps, carbon dioxide tanks, and access to the main unit turbine pits and wicket gate mechanisms; and level -10 included the fire protection and cooling water pumps. Level +23 accommodated the station service turbine pit and oil storage pit, while level +10 contained the draft tube for the station service unit. Air compressors and storage tanks sat at level -42; unwatering pumps, at level -58; and oil purifiers, at level -23. Finally, sumps used to drain excess water from the foundations sat at level -63. At the south end of the generator room (level +55), a machine shop contained a small number of lathes, drill presses, and grinders for small-scale repair work. In addition, administrative offices used by Corps of Engineers personnel operating the project resided near the top (level +95) of the powerhouse's south end.

Modernization of the electrical system used to carry and control the power produced by the generators has not altered the main features and components of the powerhouse. Continuation of this work should not affect the overall appearance of the powerhouse or any of its main components.

<u>The Original Navigation Lock</u> (OR-11-D-5)

The original Navigation Lock, located on the Oregon shore of the Columbia River, sat directly adjacent to the south side of the First Powerhouse. The lock measured 500 feet long, 76 feet wide, and had a depth of 26 feet above the lower sill at low water. At normal river level, the lock provided a vertical lift of 59 feet; at low river level it had a lift of 66 feet while at high river level the lift was 30 feet. The lock allowed passage of large barges around the Bonneville Dam/Spillway and the original Powerhouse. Navigation lock construction required blasting a deep cut through hard andesite rock. The nonmovable portions of the lock consisted of a reinforced concrete structure resting directly on the bedrock foundations. At the upstream end, two 45-foot-high, steel miter gates--each with a width of 44 feet--closed off the lock. At the downstream end, two 102-foot-high, steel miter gates--each with a width of 44 feet--were used to shut off the lock. When in a closed position, both set of gates formed a V-shaped structure pointing upstream that resisted hydrostatic pressure from water in the Bradford Slough or in the lock itself.

The lock operated by having the main chamber fill with water from intake valves located at the upstream end of the north wall. Water from the Bradford Slough of the Columbia River flowed through the intake valves and entered a 14 foot diameter channel, extending longitudinally under the entire length of the lock. Water from this channel then flowed through 41 floor ports on the bottom of the lock and was allowed to fill up the chamber to the level of the Bradford Slough. The chamber was emptied by closing off the valves at the upstream end of the lock and opening similar valves at the bottom of the downstream edge of the structure. Water in the chamber flowed back down the 41 floor ports and into the subterranean channel, from where it discharged through open valves under the wall at the base of the lock's end. If a barge coming upstream wished to pass through the lock, then the chamber was completely emptied and the miter gates opened so the vessel could enter the lock. The vessel was then moored to a floating moor bit located along the side of the chamber. Connection to a moor bit kept the vessel from moving or drifting during the filling process. The gates were then closed and water released into the chamber. When the chamber filled, the upstream miter gates opened, and the vessel continued its journey up the Columbia River. For barges coming downstream, lock operators reversed the process. They opened the upstream miter gates, allowing the vessel to enter the chamber. Then they closed the upstream gates and drained the water from the chamber. When empty, the lower miter gates were opened, and the vessel simply floated out of the lock and continued its journey downriver.

Operators controlled the original Navigation Lock from a concrete control tower located between the first Powerhouse and the downstream end of the lock. To facilitate the repair and maintenance of the miter gates, the facility also included two service cranes at each end of the lock chamber. Directly downstream from the lock, a plate girder swing bridge with a clear span of approximately 50 feet carried automobile traffic across the lower navigation channel. This movable bridge connected the original Powerhouse, Bradford Island, and the dam/spillway with the Oregon mainland and required opening every time a vessel passed either upstream or downstream through the Navigation Lock. With an expected completion date of 1992 for the new Navigation Lock to the south of the original Navigation Lock, the original facility will be taken out of service and left on "standby" in case of an emergency. The original Navigation Lock will not be changed physically by construction of the facility. However, it will no longer be necessary to operate the movable swing bridge.

The Administration Building (OR-11-B-1)

The Administration Building was located at the south side of the main entrance to the Bonneville project. Designed by Hollis Johnston, a local architect, the building was a brick and wooden frame structure constructed in a simple Colonial Revival Style. The brick, painted white and laid in plain bond, had split-brick liners placed on every seventh course. Brick quoins extended 3/4ths of an inch at each of the corners. The wooden gable roof originally had shingles, but it was later covered with a composite roofing material. A louvered cupola surmounted the roof above the central hall. Fenestration around the building consisted of a variety of window types including fixed octagon sash, single inswing sash, double window, mullion and transom, triple window, and double sash and transom.

When originally built, the structure measured 70 feet by 30 feet and included a central hall, conference room, police office, information offices, and lavatories. In 1937, the Corps expanded the building using designs prepared by P.A. Spice, an associate engineer on the Corps staff. This expansion work included building a 38 feet by 30 feet extension on the rear elevation. At the same time, 38 feet by 30 feet flanking wings were added on to both ends of the structure. Constructed in an architecturally compatible style, these additions prompted reorganization of the interior space but did not substantially alter the character of the Administration Building. Since that time, the only notable change to the building occurred during World War II when the exterior received a coat of camouflage paint. Patches of the green paint are still visible today. Construction of the new Navigation Lock will not affect the building.

The Auditorium Building (OR-11-A-20)

The Auditorium Building stands at the north side of the main entry road to the Bonneville project. Like the nearby Administration Building, Hollis Johnston designed this structure in a Colonial Revival style. Built on a concrete foundation, the Auditorium consisted of a single-story, wooden frame structure with a brick veneer. The brick, painted white, was laid in plain bond with split-brick liners every seventh course. Brick quoins extend 3/4ths of an inch at all of the corners. The terrace at the entrance is constructed of bricks laid flat in a basketweave pattern. Each of the pilasters flanking the main entrance were surmounted by cast iron, pineapple ornaments. A cast-iron grille enclosed the brick arch above the four doors in the entry bay. The original shingle gable roof subsequently was covered with composite roofing material. The fenestration included numerous octagonal, casement, and sash windows, many built with transoms.

The main part of the building measured 160 feet by 41 feet and extended lengthwise across the main front facade. A 62.5 feet by 42 feet gymnasium/auditorium room extended off of the rear elevation and gave the structure an overall T-plan. The end of the gymnasium contained a 32.5 feet by 64 feet stage-dressing and property room area. The interior of the building included a main hall, vestibule, library, club room, store rooms, gymnasium/auditorium, and various dressing rooms and lavatories. The building will not be affected by the construction of the new navigation lock.

Landscaping (OR-11-3)

The original landscape design at Bonneville included 20 acres of planned, formal and informal plantings. In 1982, the Corps altered 11 acres of this landscaping when removing the original housing development for the Bonneville project. The surviving landscaping includes a long formal entry road extending from the Union Pacific viaduct at Tanner Creek to the Auditorium. Low rubble stone walls, plantings of rhododendrons and azaleas, and tall stands of native conifer trees flanked the entrance drive. At the Auditorium Building, the landscaping opens up into a broad expanse of manicured lawn that followed a flowing, rather than rectilinear, plan. The landscaping included carefully maintained plantings of yew, juniper, rhododendron, and many other plants. Two sunken rectangular-shaped rose gardens, containing four magnolia trees, sat directly adjacent to the backside of the Auditorium Building.

Construction of the new navigation lock will affect portions of the landscaping behind the Auditorium Building, mainly the open lawn area and several of the scattered conifers. However, the overall integrity of the landscaping scheme adapted for the Bonneville project will remain unaffected.

The Bonneville Fish Hatchery (OR-11-C-1)

The fish hatchery facility of the Bonneville National Historic Landmark District lay within a four-sided, irregular-shaped tract of land bordered on the south by the Union Pacific right-of-way, by Mitchell's Ditch (Bypass Canal) on the north, by the newest hatchery buildings on the west, and by the project's main entry road to the east. This tract contained hatchery facilities completed in 1936 but did not include new structures and rearing ponds completed in the 1970s. The original 1936 incubation building, a one-and-one-half story, rectangular, wooden frame structure measuring 50 feet by 150 feet, was built in a Colonial Revival style. The building was covered with cedar siding and had centered, double entry doors flanked by small closet lights. It contained two principal incubation rooms located to the right and left of the main entrance. Six large bay windows provided interior light for the building. The plywood-sheathed interior housed numerous incubation trays used for hatching eggs. Constructed with concrete floors, the building design was extremely utilitarian, primarily intended to provide simple protection for the hatching trays against the elements. The recently renovated structure still retained its original design and finishes. None of the structures from the 1909 phase of hatchery construction exist today.

The Gardener's Building, formerly the hatchery office building built in 1936, was a rectangular, one-story wooden frame building measuring 14 feet by 32 feet. Built on a concrete foundation, the structure had sash windows and a short porch projecting above its centered main entry. Neither the Hatchery Building nor the Gardener's Building will be affected by construction of the new navigation lock.

Permanent Quarters (OR-11-25)

As a part of the original Bonneville Dam project, the Corps built a residential/administrative compound. It consisted of the auditorium and administration buildings and twenty, two-story frame houses. The architect designing the compound developed four different house plans based on the colonial revival architectural style. The structures ranged from 1,072 to 2,188 square feet in size. The site plan for the housing/administrative complex used a curvilinear street plan to fit the structures into the natural setting. Builders completed the houses in 1934 and the landscape in 1935. The Corps removed the houses in 1981 to make way for the approach to the new navigation lock.

Hydraulic Laboratory (OR-11-9)

Many problems in the design and construction of Bonneville Dam could not be solved by theoretical analysis or past experience. Solutions to these problems were sought at the hydraulic laboratory established at Bonneville during initial construction of the dam. The laboratory subsequently made studies on approximately 100 models of other multiple-purpose dams and navigation channel improvements.

At the laboratory, comprehensive hydraulic model studies were conducted on general layouts of projects while sectional models tested navigation locks, spillways, fishways, conduits, and valves. The structure and layout of each model and all hydraulic quantities were to scale ranging from 1 to 100 in the general models to 1 to 4 in tests of detailed structures. The laboratory functions were transferred to the Corps' Waterway Experiment Station in March 1982, and the buildings were razed in 1988 to make way for the approach to the new navigation lock at Bonneville Dam.

Because of the potential impacts to the Bonneville Dam Historic District from construction of the new navigation lock, the operation and maintenance activities, and modernization of the electrical and mechanical components, the Corps of Engineers, the State Historic Preservation Officers of Oregon and

Washington, and the Advisory Council on Historic Preservation entered into a programmatic memorandum of agreement (PMOA) to propertly manage the district. One of the PMOA stipulations required a Historic American Engineering Record documentation of the equipment that controlled, generated, and transmitted electricity and that operated the dam. The requirement has resulted in this comprehensive record of the Bonneville Dam Project and Historic District.

Chapter 1: Politics and Planning

The Federal Government's interest in building Bonneville Dam originated in a March 1925 Congressional directive to the Corps of Engineers recommending a study of navigable rivers across the nation "whereon power development appears feasible and practicable." The Corps was to formulate "general plans for the most effective improvement of such streams for the purposes of navigation . . . in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation." In April 1926, the Corps submitted to Congress a list of rivers deserving intensive study. This report became the now famous House of Representatives Document 308. The Columbia River and its main tributaries figured prominently in the subsequent nationwide survey conducted under the provisions of House Document 308.[1]

Prior to Federal involvement in the multiple purpose development of the Columbia River, numerous state and local organizations attempted to generate interest in such development. These groups offered competing proposals for utilizing the river's potential, focusing primarily on the potential stimulus to either the region's agriculture or industry. The State of Washington, for example, sponsored surveys and promoted a major irrigation project in the Upper Columbia Basin during the 1920s. Oregon, on the other hand, emphasized harnessing the hydropower potential of the Columbia River and its major tributaries. In 1916, the Oregon State Engineer presented plans and estimates for constructing a series of projects in the river basin to generate power, improve navigation, and provide water for irrigation. The study, entitled Oregon's Opportunity in National Preparedness, admitted that no market existed for the enormous quantities of power such projects could produce. The report argued, however, that a market could be created by developing the manufacture of nitrates for munition in wartime while making fertilizers in peacetime. The report urged that "the most logical project . . . for early construction is at Bonneville, on the Columbia." In 1929, the Portland General Electric Company made borings and prepared preliminary plans for a dam in the vicinity of Bonneville. These plans, however, never proceeded because the estimated $30 million investment was too large an undertaking for the local financial market.[2]

Between 1927 and 1931, the Portland District of the Corps of Engineers labored mightily on the elements required for the comprehensive surveys called for in the 308 report. Until the summer of 1929, initial work on the survey consisted of defining the Congressional intent as to the scope and amount of detail to be covered in the comprehensive report and an estimate of the expense involved. Based on the preliminary planning effort, the Chief of Engineers authorized the additional work needed for the comprehensive report. The compilation of data required extensive field work involving foundation investigations, stream flow studies, topographic and hydrographic surveys, and reconnaissance of irrigable and flood-prone areas. The Corps then coordinated this information with investigations conducted for the survey by the United States Geological Survey, the Bureau of Reclamation, and various specialized consultants. The final report, containing 1,845 pages, first presented the data and cost estimates for proposed projects under four elements: navigation, power, irrigation, and flood control. The report then combined the four features into a comprehensive plan with recommendations for accomplishment.[3]

In arriving at "the best plan of improvement for all purposes," engineering considerations remained secondary to the economic feasibility of the recommended projects. The North Pacific Division Engineer, Colonel Gustave Lukesh, made this point clear to his district engineers in Portland and Seattle:

> Although a plan as a whole may be wholly feasible from an engineering construction point of view, or from the point of view of meeting the requirements as to full utilization of the river's resources and potentialities, yet, unless the plan is economically feasible, it can not be recommended.[4]

The project justification contained in the 308 report reflected a real change from the 19th century rationale for Federal improvement of the Columbia River. While improved navigability of the Columbia River remained the reason for Federal expenditure, the test of public necessity had shifted. During the 19th century, Federal waterways improvements were justified if it could be argued that such work would result in the reduction of competing transportation rates and promote further regional development. By the 1920s, the weakness of such an argument became increasingly evident, especially since little or no freight acually moved on some waterways--as was the case with the Columbia above Portland at that time. As Colonel Lukesh noted, "the expenditure of funds . . . on river improvement for navigation whose only or main effect will be a reduction of rail or truck rates with the river failing to carry its quota of freight is a cumbersome and uneconomic procedure." He further noted that

> there is no gain in national assets to offset Federal funds consumed in a river improvement that leaves the river unused for actual freight movement, though there may be a benefit to a fortunate section of the public. In determining the amount of contribution of Federal funds appropriate to a river improvement no credit should be taken for freight savings unless effected on freight actually moved on the waterway.[5]

Structures built to improve navigability also had applications for power generation, and the Columbia long had been touted as a stream with vast power production possibilities. Thus, Lukesh could confidently assert that "while navigation possibilities sanction the report . . . the power possibilities of the stream may be considered the basis of this report." Potential use of the Columbia for irrigation and flood control played a less important role in the Corps' proposed plan for comprehensive development of the river. Dam construction authority would rest chiefly on power development considerations.[6]

The Corps' 308 report recommended a ten-dam comprehensive plan for the Columbia River. It designated Crand Coulee as the key upriver project and Bonneville as the lowermost in the chain. Report data on the resources and industries of the Pacific Northwest soon became dated, as did the overly cautious analysis of future regional power usage. Nevertheless, the document's concise presentation on dam sites and structures formed the basic plan for Columbia River development over the succeeding 50 years.

In their review of the 308 report, the Board of Engineers for Rivers and Harbors generally concurred in its findings but urged development of the river's power potential by private interests, states, or municipalities. The Board stated that the Federal Government's contribution should be limited to the cost of the locks and channel improvements necessary to take advantage of the slack water navigation provided by the power dams below the mouth of the Snake River. National economic events would soon make obsolete that recommendation concerning the general Government's role in financing the river development.[7]

Proposed in the early 1930s as the first Federal dam on the Columbia River, Bonneville highlighted the Columbia's potential as the greatest hydroelectric power stream in North America. About 40 percent of the nation's possible hydropower lay in the Columbia River system alone. The river's great volume and its rapid rate of fall--two to five feet per mile of flow--account for this potential. Rising in the Canadian Rockies, the river travels 1,210 miles to reach the Pacific Ocean and drains a 259,000 square mile area. The ten-dam plan described in the 308 report proposed to use for power development all but 95 of 1,288 feet of total river head below the International Boundary. As a key part of the plan, the dam and navigation lock at Bonneville were located where they would create a pool of water with a sufficient vertical fall to operate the dam's large hydroelectric turbine-generator units and with enough slack water to cover the Cascade Rapids and accommodate ocean-going vessels 48 miles upstream to The Dalles.

While engineers made plans to utilize the abundant energy of the Columbia River, the nation became mired in the Creat Depression. Massive unemployment, bank failures, bankruptcies and mortgage foreclosures, and commercial paralysis rocked the country. In the Pacific Northwest, 80 percent of the lumber mills had closed by 1932. Farm markets and income dropped, tenancy increased, and apple growers burned their trees to avoid the expense of caring for them. The 1932 presidential campaign focused on what to do about the economic collapse, with Franklin Delano Roosevelt promising a "New Deal" for the American people.

In September 1932, candidate Roosevelt spoke in Portland. He stated his interest in the "vast possibilities of power development on the Columbia River." He promised that if elected "the next hydroelectric development to be undertaken by the Federal Government must be on the Columbia River." Roosevelt personally visited, at that time, the general site of the future Bonneville Dam. While the election of Roosevelt and the clear public benefits to be gained from the Covernment investment in hydropower argued in favor of the Bonneville Dam project, other public works projects also competed for the limited funds available. Secretary of the Interior Harold Ickes opposed construction of Bonneville on the grounds that the Federal government could afford to build only one project in the Pacific Northwest and that one ought to be Grand Coulee.[8]

Only strenuous lobbying by Oregon Senator Charles McNary and Representative Charles Martin convinced the President to allocate the necessary funds in 1933. According to Martin, the President's initial enthusiasm for the project waned when questions arose about the adequacy of the foundation rock at Warrendale, the original site proposed for the dam. Roosevelt refused to commit Federal funds for Bonneville unless he could be guaranteed that a suitable foundation existed. Martin then secured an appropriation for the Corps to conduct the necessary geological surveys of the Columbia between Warrendale and Bonneville to locate a feasible site. Armed with a report from the Corps indicating that a suitable location existed at Bonneville, a few miles upstream from the Warrendale site, Martin and McNary extracted a firm commitment from the President to fund the Bonneville project. McNary later recalled about the final meeting on the matter that only "after much discussion and some urging, the President said he thought allocation funds might be made, but wanted us to see Secretary Ickes. This we did and later twenty million dollars was allocated for the commencement of the project." Amazed at Martin and McNary's success in overcoming intense opposition to Bonneville Dam within Roosevelt's inner circle, a Government official told Martin that he had missed his true calling: "You would have made a supersalesman." Undoubtedly, McNary's clout as the Senate Republican leader and close personal relationship with Roosevelt were factors in winning the President's approval. Four years later, when Roosevelt signed the legislation providing Congressional authorization for Bonneville, he explained, "I've got to give Charlie his dam."[9]

The exaggerated prose of Portland journalist Marshall N. Dana captured the hope and inspiration Oregonians felt in Roosevelt's commitment to build Bonneville Dam:

> When President Roosevelt ordered the construction of the Bonneville Dam he marked the historic moment when the Government of the United States caught the vision of the West and began to make the dreams of its great personalities come true. Began to plant, too, the seeds of those regenerative activities and influences that help to keep governments virile and civilizations strong.

Whatever the hopes and aspirations, without the timely completion of the necessary surveys, engineering studies, and economic justifications by the Corps of Engineers, local interests could not have successfully urged construction of the project.[10]

The Federal Emergency Administration of Public Works authorized Bonneville Dam on 30 September 1933 as Federal Works Project No. 28, under provisions of the National Industrial Recovery Act. When work began on 17 November 1933, the plans called for locating a dam, a powerplant with two units, and a navigation lock in the vicinity of Bonneville, Oregon. The initial allotment contained $20,000,000 for construction, and $250,000 for preliminary study and design. Before Congress formally adopted the project on 30 August 1935, putting it under the regular appropriations process, $32.4 million in public works funds had been spent. It cost another $7.5 million to complete the undertaking as originally planned. Subsequently, the Corps installed eight additional power units to complete the project at a total cost by 1943 of $75 million.

At the time of its authorization in 1933, plans for Bonneville Dam had not progressed beyond the preliminary study and investigation stage. The most vexing immediate problem involved selection of the exact site for Bonneville. Preliminary studies by various engineers between 1916 and 1933 had produced numerous possible sites over the seven-mile length of river stretching from Cascade Rapids to Warrendale. The 308 report had recommended the Warrendale site, even though it consisted of unconsolidated sand and gravel. Uneasy with this choice, Congress ordered the Corps to review the data again. As stated earlier, additional borings and geological studies at the Bonneville and the head of the Cascade Rapids locations disclosed rock foundations, causing the engineers to reject the original Warrendale site. Further analysis indicated that the Bonneville site offered "the greatest advantages as to safety, navigation and cost." Based on this finding, Roosevelt approved the Bonneville Dam project.[11]

The complex geology of the Columbia River Gorge made site selection extremely difficult. Over the millennia, volcanism and a series of basaltic lava flows had created several geological formations through which the Columbia River cut its channel, creating a gorge over 6,000 feet deep. Even as shrinkage and folding created the Cascade Mountain Range, the Columbia managed to maintain its course, eroding a gorge over 200 feet deeper than the present channel. About 800 years ago, a massive landslide three miles in width and length, at Table Mountain on the Washington side, completely blocked the Columbia. The river eventually broke through around the southerly toe of the slide, forming the Cascade Rapids. Over a course of seven miles, from the head of the Cascade Rapids to Warrendale, the river fell 37 feet. Twenty-four feet of this drop occurred in the first turbulent 2,000 feet.

Geological instability also affected the south side of the river at this location. Along the Oregon shore, the Ruckel landslide, extending two miles between the head of Cascade Rapids and Eagle Creek, resulted from continual ground movement where water flowed along the surface of the bedrock. Since backwater from a dam would saturate the toe of the slide and drown out the existing drainage tunnels constructed to stabilize railroad tracks, new work would be needed to restabilize the area. The consulting engineers and geologists determined that both the railroad and highway would require expensive and difficult relocation.

Finding bedrock beneath the slide debris proved a tricky operation. Supplemental core borings undertaken in 1932-33, however, disproved the earlier studies indicating that bedrock could not be found at suitable depths in the slide area. Additional core samples showed that bedrock at Bonneville and the head of the Cascade Rapids had gone undiscovered during the 1930 drilling because the contractor had not recovered whole cores nor distinguished the fragments of bedrock from the overlying landslide debris.[12]

While the additional studies demonstrated the superiority of the Bonneville site in meeting the combined needs of navigation, power development, and low cost, the engineers had not determined the exact location of the main spillway dam, lock, and powerhouse. The first contract, let 17 November 1933, initiated work at the north end of Bradford Island at the "Boat Rock" site. A severe winter flood halted work on 25 December 1933, however, and further exploratory drilling disclosed more suitable foundation conditions about 2,000 feet downstream. In March 1934, the Corps abandoned the "Boat Rock" locale for the new location. At this spot, two basalt intrusions or uplifts in the bedrock provided ideal foundations for the dam, powerhouse, and lock. Upstream and downstream from these ledges, bedrock dropped off precipitously. The new location also meant a savings of $3 million and shortening of the construction time by one work season.[13]

Thorough surveys and investigations by the Corps of Engineers had proven the feasibility of siting a major dam, powerhouse, and navigation lock at the head of tidewater on the Columbia. Many, including President Roosevelt, had been skeptical that a good foundation for the structures existed at that locale. The completed studies, however, gave Colonel Thomas Robins, North Pacific Division Engineer, the assurance to state flatly, "I most certainly would not have recommended construction had I not been sure of the foundation for the dam." Ten months later, on 3 August 1934, when President Roosevelt came to observe the progress on the construction of Bonneville Dam, he just as confidently predicted the future benefits to the Pacific Northwest from power generated by the Government at Bonneville:

> There is another reason for the expenditure of the taxpayers' money in very large amounts on the Columbia--a good many other reasons. While we are improving navigation, we are creating power, more power--and I always believe in the old saying, 'More power to you.' I don't believe that you can have enough power for a long time to come, and the power that we are developing here is going to be power which for all time is going to be controlled by government.

The challenge before the Corps of Engineers was to make reality of the dream, held by Roosevelt and others, that hydropower from the Columbia River would fuel the growth and prosperity of the region.[14]

Chapter 2: Design and Construction

The design and construction of Bonneville Dam had to contend with a number of engineering challenges. Planning needed to accommodate the multiple purposes of power production, navigation, and migratory fish passage in separate structures built across two channels of the river separated by an island. The unusually large annual flood discharge of the Columbia River required using the entire main river channel for the spillway. Surveys and land acquisition for the project structures and reservoir flowage had to be carried out immediately. Excavation and construction had to be accomplished between high water periods, and complete diversion of the river was not feasible. Temporary fish passage facilities had to be provided for migratory fish. Since plans for the project had not advanced beyond the preliminary study and investigation stage at the time of initial authorization, design and construction proceeded almost simultaneously.

Since Bonneville Dam was originally promoted as a means to provide employment during the depths of the Great Depression, the Portland District Engineer acted quickly to get the Bonneville Dam project underway. After the Public Works Administration allotted the initial $250,000 for design and construction on 12 October 1933, the District Engineer recruited the personnel necessary to design the project. Several prominent engineers were hired as consultants to advise the existing district civilian engineering staff. D.C. Henny and L.C. Hill, advisors on the main dam and powerhouse, had consulted previously on the Boulder and Fort Peck dams. Other nationally-known consulting engineers with expertise on dam and hydropower design included John Hogan, L.F. Harza, F.H. Cothran, J.C. Stevens, and Raymond Davis. To analyze the complex geology and carry out the necessary foundation studies, the District brought in Professors Charles Berkey of Columbia University and Edwin Hodge of Oregon State College, well-known geologists. The major in-house staff included C.I. Grimm, chief engineer; Ben Torpen senior construction engineer; H.C. Gerdes, C.G. Galbraith, R.E. McKenzie, and L.E. Kurtichanof as engineers in charge of dam, powerhouse, lock and electrical design, respectively.[1]

To expedite employment on construction work, District Engineer C.F. Williams divided the work into a large number of contracts. As promptly as the project plans could be developed and assembled into discrete contracts, the Corps advertised and awarded each separately. Before contractors could excavate for the spillway, powerhouse, and navigation lock, the Government had to clear land, relocate railroad and highway routes, and construct a work camp. The Corps started construction of a 400-man camp with hired labor on 1 November 1933 and awarded the first relocation contracts on 17 November and 29 December 1933. The Corps issued the first principal contract, involving excavation for the lock and powerhouse, 6 February 1934 for $1.1 million. Between the excavation contract and the $8.9 million main dam contract let on 12 June 1934, the Corps awarded seven miscellaneous contracts amounting to $1.2 million. The following month, the Corps accepted a $3.8 million bid for building the lock and powerhouse substructure. Other construction contracts awarded before the end of 1934 amounted to $.8 million. In addition to the first-year contract work, the Government hired a large force for non-contract labor. When the project was fully underway, the total work force averaged about 3,000, with skilled workers earning a minimum hourly wage or $1.20 and unskilled workers, $.50.

The Corps needed 800 acres of land below Cascade Locks for the main structures, sites for temporary and permanent buildings, railroad and highway relocations, construction work areas, and reservoir flowage. In addition, above Cascade Locks, the reservoir pool would cover or periodically overflow another 52,000 acres. Surveying, appraising, and acquiring these lands proved a tedious and time consuming process. Since flowage affected approximately 70 square miles, the Corps had to run 700 miles of survey lines to make an official survey of the area. Ultimately, the Corps had to resort to condemnation to acquire all the property it needed.[2]

Building the spillway dam in a narrow channel passing a large flow presented complex hydraulic problems. To solve these issues, the Corps established a hydraulic laboratory and constructed a 1 to 36 scale model of three spillway gates and a 1 to 100 scale model of the river from the dam sites to the head of the Cascade Rapids. Initial studies focused on the best means of dissipating the energy of the flow over the spillway crest and the dam's effects on backwater elevations. The object of the first study was to prevent erosion of the bedrock below the dam, and of the second, to limit flowage damage.[3]

Based on geologic and hydraulic studies, two main concerns governed the design of the spillway dam. The structure had to achieve stability on the comparatively weak foundation rock at the site, and it had to pass a large flood without causing a material rise in head water elevations during floods. The engineering design protected the sill against sliding and the effects of shear or scour by providing sufficient structural weight and by forming the foundation in large steps or notches parallel with the lines of stress. To cope with the destructive power of the falling water from the spillway, the engineers placed a double row of reinforced concrete baffles on a specially designed overflow section on the deck and used a heavily reinforced, five-foot thick concrete apron extending 100 feet at the toe of the dam.

The engineers dealt with the wide variation in streamflow by using a relatively low sill and handling the overflow with exceptionally large steel gates set in deep slots between reinforced concrete piers. The piers were capable of withstanding large direct and side pressure from a combination of open and closed gates. To determine the optimum spillway gate size for handling anticipated flood flow, ice, and drift, the Corps' engineering team under H.G. Gerdes carefully studied other recently constructed dams, as well as Columbia River hydrology. Based on their analysis, the engineers decided that 50-foot wide gates, opening at two-foot intervals could safely handle regulation of the pool behind the dam.

The engineers also sought a mechanical design which would provide safe, durable, and simple mechanisms for all gate operations. In the interest of economical construction and operation, the engineers designed each gate to be built in two parts at a foundry and then joined into single units at the dam for placement in the spillway slots. In operation, each gate moved on 26 enclosed roller-bearing wheels. Both the lifting and latching devices for operating the 200-ton gates were controlled from one of the two 350-ton gantry cranes. All mechanical designs developed by the engineers incorporated the latest advances in metallurgy, specifying stainless and nickel cast steel for load bearing and moving parts. In fabricating the gates, they required silicon steel for the horizontal girders and carbon steel for the skin plates and smaller bracing.

As built, the gravity concrete spillway dam reached 1,450 feet in overall length with eighteen, 50-foot wide gates. Twelve of the gates were 50 feet high and six were 60 feet. The base of the dam measured 132 feet and the height above the lowest point, 197 feet. The spillway design, placing 50-foot high gates on a low weir sill at elevation +24, created a normal pool elevation behind the dam of 72 feet above sea level with 2 feet of freeboard. When raised to their full open position, the spillway could pass a flood of 1.6 million cubic feet per second--37 percent greater than the maximum recorded flood of 1894. The gates and cranes cost $1.2 million.

To help the spillway pass large streamflows without raising historic flood elevations, the Corps increased channel capacity for three miles upstream by blasting and excavating obstructing rocks. In addition, the engineers widened the channel on both the Bradford Island and Washington shores at the dam axis, increasing the width from 800 to 1,200 feet by removing 954,293 cubic yards of material. Reinforced concrete cutoff walls at each abutment and reinforced concrete counterfort type upstream wing walls, along with downstream training walls, provided further safety for the spillway structure from the destructive forces of the river. Since the foundation rock was lower at the ends of the dam, the abutment walls had to be built over 150 feet high. The Columbia Construction Company began work on the spillway dam in June 1934.[4]

The powerhouse, located near the lower end of Bradford Island to take advantage of an andesite foundation, originally provided for two hydroelectric generating units with substructure for four additional units. Excavated to a depth of 58 feet below sea level, the powerhouse initially was to house only two units and a station service unit; but even before these units began operation in March 1938, the Corps expanded the superstructure to accommodate four more units. As finished, the reinforced concrete powerhouse extended 1,027 feet in length and 190 feet in width and height (roof to bedrock). Piers 10 feet thick separated the units, forming initial intake openings 65 feet high and 62 feet wide. Each draft tube throat had a diameter of 23 feet and each turbine hub measured 8 feet. The initial two turbines carried a rating of 66,000 horsepower (h.p.) and the remainder, 74,000 h.p. The first two generating units produced 43,200 kilowatts (kw) each, while the remaining units were rated at 54,000 kw. The ultimate total output of this first powerhouse (518,400 kw) would have satisfied the electrical needs of a city three times as large as Portland in 1935.

The engineers based the general design of the powerhouse on the need to handle large quantities of water at comparatively low head. This required large intakes, concrete scroll cases, and deep draft tubes. Each generator was equipped with the Kaplan adjustable-blade propeller type of turbine. Engineers selected this kind of turbine because of space constraints at

Bonneville and the wide seasonal variation of head at the powerhouse. The Kaplan turbine required less space per horsepower than other types of turbines and achieved maximum efficiency under a wide range of load and head. Twenty wicket gates on each unit let water into the turbine. An automatic governor on the units simultaneously adjusted the wicket gates and turbine blade angle to compensate for the variation in load. Each turbine unit weighed 900 tons and had a main shaft diameter of 40 inches. Each possessed a discharge capacity of 13,000 cubic feet of water per second--enough water to fill an average three-bedroom house. Vertical shaft type generators connected directly to the turbines and exciters which, in turn, were linked through a control station with the transformers on the upper deck of the powerhouse. The high tension switch yard equipment was located on the roof of the powerhouse.[5]

The electrical engineers worked under difficult circumstances, with the design and construction of the powerhouse structure occurring before the actual electrical load and means of meeting it had been determined. The engineers had to design a plant without knowing the precise type of equipment which would be used. Construction was pushed along at a frantic pace. According to at least one frustrated electrical engineer, "the only objective apparently being the dumping of yards of concrete and the placing of tons of steel. Structural design in the office was but a jump ahead of actual construction in the field."

Bradford Island served as the connecting link between the dam and powerhouse. The engineers, however, found it necessary to raise the height of this natural earthen dam by means of a 2,000-foot-long impervious levee and cutoff wall. Part of this wall was later removed when workers expanded the powerhouse to accommodate four additional units beyond the initial six. The contractor, Guy F. Atkinson Company, began excavation for the powerhouse and navigation lock under a single contract in February 1934.[6]

Several changes occurred in the navigation lock plans as they evolved. Preliminary designs called for a tandem lock with a short canal adjacent to the powerhouse along the Oregon shore. The dimensions of the lock chambers were set at 56 by 30 feet, sufficient for existing barge traffic. Soon, however, a combination of geology and politics produced changes in the original plans. The Chief of Engineers opposed construction of a ship lock on the grounds that current and potential commercial use did not justify the added cost. But on 28 December 1933, he gave in to political pressure and agreed to widen the lock chamber to 76 feet so that barges could be handled two abreast. Based on additional borings indicating that the andesite base at the lock could accommodate a single-lift structure, the Corps decided, in February 1934, to adopt a single lift design.

While Roosevelt had backed the Chief of Engineers' finding against a ship lock at Bonneville, the President had agreed to reconsider at a later date if conditions changed. Local Northwest interests kept up the pressure to reverse his decision. In April 1934, Representative Charles Martin got the House River and Harbors Committee to authorize the Corps to study the feasibility of providing a 30-foot ship channel between the mouth of the Willamette River and Bonneville Dam. After prodding by Senator McNary, the Corps agreed to take another look at the feasibility and cost of constructing a ship lock. Based on this review, carried out in the summer of 1934, the Corps discovered that

$2 million could be saved by building the ship lock initially, rather than barge locks which would be converted at a later date. When Roosevelt arrived at Bonneville on 3 August to view the progress on the project, he signalled his receptivity to a ship lock if justified by the Corps studies. To the welcoming throngs at the dam site, he clearly expressed his hope that "it will be found the part of wisdom to enlarge the locks at Bonneville so that sea-going ships may find practical passage up the Columbia as far as The Dalles." On 15 August 1934, the Secretary of War, bowing to the political pressure and the Corps' assurance that a ship lock was feasible, authorized construction of a single lift ship lock 76 feet wide, 500 feet long, and 24 feet deep over the sill at low water. These dimensions would accommodate 8,000-ton ocean-going vessels. Having a vertical lift of 60 feet made the Bonneville lock the highest single-lift lock built to that time.[7]

The design called for excavating the lock chamber out of solid andesite rock and covering exposed wall surfaces with concrete anchored to the rock. The engineers conducted numerous model experiments before arriving at a system for filling and emptying the lock. The final design called for filling the lock by opening tainter valves located in the upstream end of the north wall. These valves connected with a culvert system beneath the lock floor which fed 41 floor ports. Water emptied through the same port and culvert system, which for drainage led to tainter valves near the lower end of the lock. The lower valves, in turn, discharged through floor ports downstream from the lower gates. Normal filling and emptying required 15 minutes.

The electrically driven silicon steel miter gates at the upper end reached a height of 45 feet, while those at the lower end were 102 feet high--as tall as a 10-story building. The downstream gate leaves weighed 525 tons each. Emergency dock closure could be accomplished by lowering 13 steel bulkheads into recessed wall grooves. The plans called for all lock machinery to be electrically operated. An unusual feature of the navigation lock involved the use of six floating mooring bits in the lock walls. Designed by the Assistant Chief of Engineers, Brigadier General John Kingman, the floating fixtures enabled small craft to overcome difficult and dangerous moorings at low stages of the river. Finally, 500-foot-long concrete guide walls at each end of the lock enabled vessels to tie up while awaiting passage.[8]

The actual construction of the dam itself posed severe problems. The depth of water, current velocity, and harsh weather conditions together with the annual summer flood presented challenging conditions. The working season was effectively limited to an 8-month period from August to March. At the close of each working season, construction had to reach a stage permitting safe abandonment during high water. After extensive hydraulic studies, which also took into account the time and weather constraints, the engineers adopted massive timber cofferdams as the best means of diverting the river from the work site. Their plan called for dividing the river in half and unwatering each half successively. First, a horseshoe-shaped timber crib cofferdam enclosed the south half of the spillway section site. After the south spillway's partial construction during the 1935-36 low water season, the workers removed the cofferdam and the river flowed between the piers over the uncompleted crest sections while another cofferdam was put in place for work on the north section. Following completion of the entire north section during 1936-37, the contractors placed a prefabricated structural steel cofferdam over the crest section between the piers of the uncompleted south portion so that those units could be brought to final elevation. Workers finished the spillway dam, including gates and gantry cranes, by June 1938. Each cofferdam consisted of three lines of cribs, forming an open "U" with shore arms diagonal to a river leg 460 feet long.

A unique feature of the crib cofferdam method of construction involved the need to "tailor" the crib bottoms to fit the irregularities of the riverbed. Since leveling the work site would have resulted in excessive cost and time loss, the engineers decided to dredge the thin boulder and gravel overburden and place the cofferdam directly on the exposed bedrock. After sounding on 2-foot centers and plotting the riverbed contours, the contractor carefully constructed the cribs to fit the bottom. Built of 12- by 12-inch timbers bolted together in horizontal courses, the 21 cribs generally measured 60 by 60 feet and reached up to 75 feet in height. The construction crews built the lower portions of the cribs on shore skidways and then floated them into position in the river. Laborers then completed the cribs to full height and sank them by dumping rock and impervious material into their cavities. After filling, the cribs were decked to prevent erosion of the fill when overtopped by the annual freshet. Workers then placed a protecting wall of steel sheet piling on the river side of the cribs and blanketed the shore cribs with an impervious outside fill.

The job of designing, building, and placing these huge structures--each approximately as large as a six-story apartment building--in the 900-foot wide river channel with a depth of 20 to 50 feet of water flowing from 6 to 9 feet per second, severely tested the capabilities of the engineers and contractors. For example, the stress from the crib holding lines in a 9-foot per second current approximated 300,000 pounds. To cope with the high current velocity, the engineers anchored the midstream line of the cofferdam directly on partly exposed bedrock near the center of the channel. The first cofferdam, though submerged by the annual flood of 1935, survived without suffering material damage. The Corps was less fortunate the following year when the annual flood partially washed out the second cofferdam. The contractors, concerned by the unusual size and potential cost of the cofferdams, refused to bid without plans. As designed by George Gerdes, chief engineer for the main dam, the cofferdams cost $2.5 million and consumed 8 million board feet of timber. At the time, it was the largest cofferdam job attempted on a United States river and attracted keen interest from the engineering community.[9]

Excavation for the powerhouse and navigation lock site followed a more traditional approach than required for the dam. In February 1934, the contractor commenced unwatering the entire work site by placing clay-faced earthfill dams, one upstream and one downstream from the foundation area, and pumping out the water. The contractor located the pumping plant outside of and below the lowest points of the powerhouse and lock excavation, a great assist in keeping the work areas dry. Upon completion in March 1934 of the contract to temporarily relocate the railroad tracks occupying a portion of the lock site, workers began blasting rock for the lock chamber. After extensive blasting, the contractors removed 741,960 cubic yards of rock and debris from the powerhouse and lock site. The Corps and contractors used over one million pounds of explosives on the entire project, the largest volume in preparing the powerhouse foundation and navigation lock site. The Bonneville Dam Chronicle observed that "the men handling the explosives became so clever that they could dress down the side of a wall as neatly as a stone mason working with tools."[10]

Work on the powerhouse substructure began 16 July 1934, the first concrete being placed in the foundation on 9 September. This initial concrete filled deep potholes extending 50 feet into the bedrock. The river created these holes during an earlier geologic era when it flowed directly over the area. Workers completed most of the lock chamber excavation during December 1934. Because of the depth involved, the contractor had to install a "More Trench" wellpoint system to dry up wet excavation areas at the east end. This drainage system consisted of deep set pipe wells located around the excavation area, intercepting the flow of groundwater and pumping it to the surface. By June 1935, when high water slowed work, about 55 percent of the lock and 90 percent of the powerhouse substructure had been finished. As the substructure neared completion in October 1935, the Corps let contracts to erect the powerhouse superstructure and to design and manufacture the turbines, generators, and other electrical components of the plant.[11]

Construction of the powerhouse superstructure, awarded 31 October 1935 and carried out by the General Construction Co. and J.F. Shea Co., proceeded without disruption until the first two units went on line in May and July 1938. Increased power demands caused work to begin on four additional units in the fall of 1938. Two of these units came on line in December 1940 and January 1941. Expansion of the powerhouse foundation and superstructure for the final four units delayed installation of the last two of the initially-authorized power units. The delayed units went into operation in September 1941 and May 1942.

In the fall of 1939, rapidly escalating power needs had prompted the decision to extend the powerhouse to accommodate the final four units. This action had been authorized by Congress in August 1937 when it approved completion, maintenance, and operation of the Bonneville project by the Corps of Engineers. The powerhouse extension proved a difficult undertaking. Considerable overburden and an earthfill dike connecting the structure with Bradford Island had to be removed and the extension carried out without disrupting power generation. Plans called for earth and rockfill cofferdams which, once in place, proved less than water tight. At one point work ceased for several days when a war shortage of parts caused water pumps to fail and allowed the site to flood. Major General Cecil Moore, the District Engineer, later recalled that "it was a great relief when they finally got the excavation done and the base foundation in down there because if that thing had gone out, well, then you would have lost . . . that whole powerplant." Workers completed the powerplant in 1943 and by December of that year the final unit went on line.[12]

The location of the navigation lock and the size of the pool behind the dam required substantial railroad and highway relocation work. To lessen the extent of relocation and increase the safety of navigation in the channel three miles above the Bonneville Dam, the engineers blasted 118,600 cubic yards of material in the rocky areas of the Cascade Rapids. Removal of this material dropped the flood stage elevation, reducing the area inundated by the Bonneville project. Moreover, if left inplace, the rocky areas would have endangered navigation upon completion of the dam. Even with this and subsequent shore and channel work requiring removal of another 281,908 cubic yards of material, the engineers had to raise the Union Pacific Railroad track on the Oregon side 35 feet for a distance of 4 miles. On the Washington shore, the Corps had to move the Spokane, Portland and Seattle Railway 7 feet over a 5-mile-long grade. In addition, sections of Washington State Highway 8 had to be moved to higher ground.

To accommodate the new Union Pacific line, the engineers built a 620-foot concrete-lined double track tunnel through Tooth Rock and a 900-foot double track earth-filled spandrel arch concrete bridge over Tanner Creek and the State Fish Hatchery grounds. In addition, the Corps had to devise a method for stabilizing a troublesome slide area, known as Ruckel Slide, over which the railroad passed on the Oregon side. After extensive geological investigations by core drilling, test pit, and tunnelling, the Corps adopted the approach previously worked out by the railroad, but on a more extensive scale. Over a one-by-two-mile area, the Corps located all water pockets and drilled several drainage tunnels to draw off the underground water flow that was causing land movement. The longest tunnel reached 2,200 feet back from the river's edge. To prevent the instability stemming from high-water erosion at the toe of the slide, the engineers placed a heavy blanket of riprap. The relocation measures, carried out during 1934 and 1935 at a cost of $5 million, proved effective.[13]

The development of a ship lock at Bonneville Dam and a channel for ocean-going vessels from Portland to The Dalles required adjustments to two bridges in the Bonneville Dam pool. The toll bridge, popularly known as the "Bridge of the Gods," which crossed the river at Cascade Locks, and the Hood River-White Salmon Bridge upstream did not provide sufficient clearance for ocean vessels. To achieve the necessary headroom under the toll bridge, the Corps supervised strengthening and extending the bridge piers so that the center section could be raised 44 feet. Workers accomplished this feat, using four 500-ton jacks. The project was completed by building new approaches on both sides of the Columbia. The Hood River Bridge renovation required a different solution, since raising the span proved uneconomical. After study, the Corps devised plans for installing a lift span to gain the needed 135-foot clearance at ordinary pool level. Reconstruction work on both bridges, funded by the Federal Government, came to $1.1 million.[14]

Construction of the Bonneville Project involved placing about 1,000,000 cubic yards of concrete. To successfully accomplish this work, the Corps had to select, manufacture, and place a cement which would withstand the various structural and environmental forces to which it would be subjected. The design of the dam and the conditions of construction required a cement of special qualities. Since the ratio of the dam's base to height was large, producing low compressive stresses, the concrete did not need high strength. The structure, however, did require great tensile strength so that it could resist the cracking that stemmed from stresses generated by temperature changes within the hydrating concrete mass. Desiring to speed construction, the engineers planned to place the concrete in five-foot lifts, with three days between successive lifts. To permit removing the forms this quickly, the cement had to be capable of setting rapidly. Construction would be occurring under low temperatures (40 to 50°F), however, which would tend to retard hardening. Therefore, under the prevailing conditions, the concrete had to have a low ultimate heat of hydration but generate as much as possible of its total heat of hydration during the first three days to speed early hardening.

To minimize volume changes due to heating and cooling, the cement mixture had to be as lean as possible without sacrificing strength or impermeability. Finally, to maintain homogeneity and resistance to weathering over time, the cement had to have low water gain and avoid segregation of the aggregate.[15]

Extensive tests of the chemical and physical properties of various cements by University of California consultants led them to recommend portland-pozzolan cement for the dam. Compared with the cements used to build Boulder and Norris dams, portland-pozzolan possessed improved workability, freedom from segregation and water gain, and a greater degree of impermeability. In addition, it had a more rapid rate of heat generation at early ages and less ultimate heat of hydration, greater tensile and compressive strength, and long continued gain in strength coupled with greater resistance to weathering and rough water action. At the time of its selection for the Bonneville Dam, builders had made little use of portland-pozzolan cement in mass-concrete construction in America. Many hydraulic structures in Europe had employed it with satisfactory results, however. Because of limited experience with portland-pozzolan, the consultants urged the Corps to develop precise specifications and implement a stringent testing program to assure the use of consistently high quality cement.[16]

To carry out the consultants' advice, the Corps established a separate concrete division at the project to conduct laboratory testing, check the quality of materials and the design mixture, and inspect all operations connected with manufacturing and placing the concrete. Several steps comprised the actual mixing and laying of the concrete. Suppliers delivered cement by rail to the contractor's mixing plants on the Washington shore and Bradford Island. Gravel aggregates for the lock and powerhouse cement came from the Willamette River, while sand and gravel deposits at Bingen and Rabbit Island on the Columbia River were mixed in the dam cement. To satisfy the different structural characteristics of the project, the concrete division ultimately developed several different mixtures, based on varying the aggregate size. The spillway dam required seven mixtures, while the powerhouse, navigation lock, and other structures needed fourteen blends. Corps inspectors carefully oversaw each stage of the process, including the preparation and blending of aggregates and the final batching and mixing process which produced the correct cement mixtures.[17]

Initially, the concreting gangs experienced numerous mechanical problems and management delays for several weeks before perfecting the pouring process. Inspectors, in the early construction period, criticized the excessive failures of concrete forms, "due mainly to improper design of forms and poor workmanship in erecting and anchoring them." Workmen constructed the spillway dam in blocks. They placed concrete in five-foot lifts, starting at the downstream apron and moving through the baffle deck, main dam, and upstream apron of each block of the structure. After placing forms and necessary reinforcement, laborers carefully cleaned the old concrete surface or rock foundation. The concrete gang then covered each lift with a one to two-inch layer of grout prior to dumping the main load of concrete. The grout consisted of cement and sand in the same mixture as the concrete, but without gravel.

The concrete crews, made up of 10 to 20 men, placed the concrete by bottom dump buckets of 8-cubic yards capacity. Two cableways rated at 25 tons capacity hauled these buckets to the point of placement. After dumping the concrete, the workers then used vibrators to puddle and compact the concrete into 18-inch thick layers until filling the form and bringing the lift to grade. The layer depth varied in reinforced sections, depending on the dimensions of the member and the amount of reinforcement and fittings in the form. The curing system consisted of garden hose sprays at 10 foot intervals over the area being cured. The sprays were connected to a pipeline conveying river water. To protect the fresh concrete from rain, the engineers developed a covering system consisting of 5- by 10-foot, light wooden frames, covered with canvas and supported 3 to 6 feet above the surface.[18]

Although the engineers used different aggregate supplies, physical plant and cement (standard portland cement) to construct the powerhouse and lock, they employed mixing and placing methods similar to those used in the spillway dam. After the required cleaning and grouting of surface areas, concrete was transported to the work site by either cableway bottom-dump buckets or pumpcrete machines. Concrete gangs averaging 15 men placed the concrete in slumps of 2 to 4 inches, vibrated and then cured the lifts with hoses or a pipe spray system. The contractor experienced fewer form failures than in the spillway dam, even though special care was needed to keep the massive amount of reinforcing steel at least 2 inches from the form faces.[19]

Impressive by daylight, the concreting process took on added drama at night. A newpaper reporter witnessed the operation in awe, describing the scene as "too impressive to be told in everyday language":

> Lights everywhere, great floods of light that make an oasis of brilliance in the darkness of the night. In the background, dimly visible, black masses of the steadfast mountains, undisturbed by this noisy confusion made by puny men, moving like busy ants about the depths of the river's forsaken channel. Nearly 100 feet below sea level they (pour) tonight -- monster buckets of concrete dangling from twin high lines, swiftly carried, carefully lowered to find the precise spot in the excavation for which they are intended. A bucket emptied of its 16-ton burden swings over to the north bank for a reload. As it descends a toy-like train runs out on its track to meet it. Swiftly a chute leaps out from the car, a cataract of concrete flows into the yawning bucket and . . . another contribution is on its way to the building of the Bonneville dam.[20]

To ensure the highest standards in the required structural steel work, the Corps established a special inspection unit in September 1935. As one engineer noted, Bonneville Dam was not a leisurely "rivet tapping" job:

> Tolerances are limited in certain instances to 0.01 inches in 5.0 ft. . . . Then, in order to expedite operations, it has been necessary to carry on construction simultaneously with design and detail.

Since important structural connections were welded, the Resident Engineer decided to test all welders to establish a uniform quality of work. Even tools and equipment demanded special attention. Standard tools lacked sufficient precision, so that it became necessary to design special devices to control and coordinate all measuring tools. The 15 man inspection squad consisted of engineers and technicians expert in precision measurements and welding. They covered the dam site 24 hours a day and the powerhouse, 16.[21]

To efficiently manage the complex and diverse tasks involved in building Bonneville Dam, the Portland District underwent reorganization. As a first step, the District established a five-man resident engineer's office at the dam site in October 1933. By December 1935, this office had grown to 21 people, overseeing contract work in progress, preparing quantity estimates for payments, and providing general engineering support. The growth in numbers of employees on the Government payroll at Bonneville reflected the pace of dam construction:

1 November	1933	- 65
1 May	1934	- 285
1 November	1934	- 555
1 May	1935	- 580
1 January	1936	- 880

The first Resident Engineer had been a civilian, but in October 1934, Captain J. Gorlinski replaced him and Captain Colby Myers became Gorlinski's assistant as Administrative Officer. Gorlinski remained at Bonneville until his transfer to Washington, D.C., in May 1936.[22]

As construction went into full swing in May 1935, the Portland District split into two units. The First Portland District remained in Portland with jurisdiction over the Willamette and lower Columbia Rivers and coastal projects, while the Second Portland District had responsibility for the Bonneville Dam construction, the Snake River Basin, and the Columbia River Basin between the mouth of the Snake River and Vancouver, Washington. In July 1937, the names of the units were changed to the Portland, Oregon, District, and the Bonneville, Oregon, District. In 1941 after completion of the dam, the Bonneville District reconsolidated with the Portland District.[23]

The Corps realized that the huge influx of laborers would overwhelm the limited housing available in the small rural communities in the vicinity of the work site. To meet this shortage, both the Government and major contractors built temporary accommodations for the large work force employed on the Bonneville project. By the end of Janaury 1934, the Government camp consisted of a bath house, kitchen, main office, hospital, and six dormitories. Over the next year and a half, the camp expanded to include test laboratories, warehouses, miscellaneous shops, 17 dormitories, and enlarged mess and office facilities. The Government later took over 13 bunkhouses built for the contractor's use. All quarters measured 20 by 40 feet. At the peak of employment (spring 1935), the Corps put up nine, 10-man tent houses to supplement the previously built quarters. By March 1934, the Government also had completed a 400-man camp for the contractor's force, consisting of 36 bunkhouses, 2 bath houses, and mess facilities.[24]

To provide living quarters for the permanent operating force, the Corps built a planned residential community on the Oregon shore west of the navigation lock and powerhouse. The buildings, designed by Portland architect

Hollis Johnston in the colonial revival style and landscaped to enhance the beauty of that section of the Columbia River Gorge, consisted of twenty, two-story frame houses, an administrative building, and a recreation/auditorium structure. The site plan laid out the streets in a curvilinear pattern to fit the natural contour of the site and placed all water and sewer lines underground. In the spring of 1934, the Government work force dug the foundations, and private contractors completed the residences in November 1934 and the auditorium and administrative buildings in May 1935. After experiencing some weather delays, contractors completed the landscaping, utilities, and streets by June 1935. The total cost of the Government community came to $402,884.[25]

Labor employed on the Bonneville Dam project came chiefly from the relief rolls in Oregon and Washington, with a preference given to ex-servicemen in Skamania County, Washington, and Multnomah County, Oregon. The Corps apportioned the work force between Oregon and Washington based on the estimated percentage of project funding spent in each state. This formula allowed one Washington worker for every five Oregon hirees. To provide commercial services for the workers residing at or near the Government work site, the Corps built a structure to house a movie theater, grocery, drug and dry goods store, cafe, barbershop, and recreation hall. Private businesses leased the various concessions. The Government organized a police force, called the United States Guards, to protect property, maintain order, provide fire protection, direct traffic, and conduct public tours. The latter two duties proved the most onerous, as over 300,000 visitors thronged the work site prior to December 1935. Allowing the public to safely view a project of such magnitude without hindering the ongoing work challenged the ingenuity and tact of the guards. At the time of its organization, the U.S. Guards constituted the first Federal police force of its kind.[26]

The Corps accomplished closure of the spillway dam in September 1937. At this time, top civilian and military figures in the National Government formally dedicated Bonneville Dam. Before a large crowd and assembled dignitaries, President Roosevelt dedicated the dam to "a policy of the widest possible use of electricity," and to "more wealth, better living and greater happiness for our children." The contractor finished the navigation lock early in 1938, and by March of that year, the first two generators produced power.[27]

The official opening of Bonneville Dam took place on 9 July 1938. The formal ceremony included such Corps officials as Major General Julian L. Schley, Chief of Engineers; Colonel John C. H. Lee, North Pacific Division Engineer; and District Engineer, Major Theron Weaver. Secretary of the Interior Harold L. Ickes threw the switch delivering electricity to the City of Cascade Locks, the first customer for Bonneville power. Great fanfare marked the passage of the first ship through the navigation locks in June 1938. When the water in the lock reached its full height, the crew of the S.S. Charles L. Wheeler, Jr. performed a flag ceremony on the deck of the ship. As the ship passed through the locks, the master of cermonies proudly announced to the assembled crowd: "Ships are now passing through the heart of the Cascades Mountains and entering into the Inland Empire."[28]

Total construction cost of the project ultimately came to $83,000,000. Some had argued, at the time of construction, that investment in such a project would be a waste of money. As BPA administrator J.D. Ross noted to President Roosevelt in 1938, "there has been a tremendous propaganda trying to picture Bonneville and Coulee projects as white elephants." To the President, Ross confidently asserted that "the operation of Bonneville . . . is going to dispel the manufactured remarks of these crepe hangers." An article in the June 1937 issue of Collier's entitled "Dam of Doubt" claimed that there was no "real need for Bonneville," and that "there . . . [was] no market remotely in sight for the power" from Bonneville Dam. The article suggested the possibility of "fine concrete monuments scattered up and down the wilderness of the Columbia Gorge, still being paid for by the taxpayers." Events soon proved the critics incorrect.[29]

Chapter 3: Hydroelectric Market and the War Effort

The Corps of Engineers' construction of Bonneville Dam and the Bureau of Reclamation's development of the huge irrigation and hydroelectric project at Grand Coulee made available vast amounts of Federally-produced hydroelectric energy. Long before these projects had been completed, distribution of their power became a controversial issue.

New Deal planners in the Pacific Northwest wanted a single agency, such as a Columbia Valley Authority, to generate, market, and transmit the electric power. Others preferred to separate the various functions among several agencies. In the case of Bonneville Dam, the latter interests wanted the Corps of Engineers to operate the dam and simply sell the project power at the generator bus to whomever would purchase it. Another, related, controversy swirled around the price to charge for the power. Colonel Robins, North Pacific Division Engineer, opposed a uniform rate for the sale of Bonneville power, arguing that it would drive up the average cost of power and thus discourage industry from locating in the region. Cheap power rates were seen as the region's best lure in the competition for electro-chemical, metallurgical, or pulp paper industries. In this same vein, the Portland Chamber of Commerce wanted a cheap rate for power as far as the Portland-Vancouver area to encourage industry to locate there but higher rates for greater transmission distances. People everywhere in the region argued instead for a blanket or uniform rate, regardless of the distance from the dam. The latter group wanted the power distributed for maximum regional benefits.[1]

Since Oregon would be the main beneficiary of Bonneville electricity, the State was determined to have a major voice in any power pricing and distribution scheme eventually implemented. Beginning in 1935, the State set about formulating its position. In that year, the Oregon State Planning Board studied the cost of delivering wholesale Bonneville power to all substations in the State. The Board found, based on Corps-supplied data, that if costs were allocated on the relative distance of transmission, power in the Portland area would be available for $14.25 per kilowatt year. On the other hand, if costs were set as a single unit throughout the entire territory served, power in Portland would increase to $19.50 per kilowatt year.[2]

During 1936, the Planning Board developed a forecast of future power demands, indicating that Bonneville's generating capacity would be totally absorbed within nine years. With proper planning and marketing, the Board saw Bonneville power as a means to stimulate industrial development and end the State's colonial economic status. Oregon's economy, it stressed, depended heavily on raw material production and export, and on the import of manufactured goods. As the Planning Board put it:

> If Oregon continues as a state, producing chiefly raw materials, exploiting its land and mining its soils, its future will follow the same direction as its past. Its people will remain at the mercy of outside economic conditions, with their purchasing power dictated by prices prevailing for raw materials in world markets.[3]

The Planning Board sided with those in the State who hoped to induce the establishment near Bonneville of industries needing large quantities of cheap power. Accordingly, the Board recommended selling Bonneville power on a variable rather than blanket rate schedule. With great foresight, the Board also recognized the unique scenic and recreational values of the Columbia Gorge and urged the adoption of safeguards to prevent industrial development from irreparably damaging them.[4]

Governor Martin of Oregon strongly backed the findings of the Planning Board and their goal of using Bonneville power to promote the industrial development of the Portland area. Moreover, he recognized that, regardless of the ultimate pricing adopted, Oregon could not benefit from Bonneville power without timely construction of a transmission system. Accordingly, in April 1935, Martin urged the President to decide on transmission lines from the dam, so that the power could be utilized as soon as available. Oregon's powerful Senator Charles McNary, while sympathetic to the Portland area's economic concerns, defended domestic consumption of Bonneville power as its highest and best use. As minority leader and confidante of the President, McNary worked tirelessly with his Oregon constituents and Roosevelt's administration to craft legislation promoting broad and equitable regional access to Bonneville's electrical output.[5]

The Bonneville Project Act, guided through Congress by Senator McNary and signed by President Roosevelt in August 1937, settled the question of marketing Federal power in the Northwest. The Act assigned the Corps of Engineers responsibility for generating the power but rejected proposals simply to sell the power at the dam site to those able to come and get it. Instead, the legislation created a Federal marketing agency, the Bonneville Power Administration (BPA), to sell power in accord with the policy of "widest possible use of available electric energy." The law gave preference to publicly and cooperatively owned distribution systems. Roosevelt and McNary designed the terms and conditions of the sale of hydroelectricity by the BPA to prevent monopolization of this vital resource by limited groups. The performance of the Bonneville Power Administration would provide a "yardstick" by which the activities of other electric utility systems in the Pacific Northwest could be measured.[6]

Congress established the BPA as a bureau of the Interior Department. The BPA administrator was empowered to construct and operate necessary transmission and substation facilities and to enter into 20-year duration power contracts. The administrator also had authority to set rates consistent with the policy of the Act and sufficient to reimburse the United States Treasury for the costs of power generation and transmission facilities. Congress further ordered that the Federal Power Commission determine the cost allocations and approve rates. New Deal planners, however, did not consider this legislation the final word on regional power policy, for one clause stated that "the form of administration herein established for the Bonneville Project is intended to be provisional pending the establishment of a permanent administration for Bonneville and other projects in the Columbia River Basin." In 1940, the President issued an executive order giving BPA marketing responsibility for Grand Coulee power.[7]

Under J.D. Ross, the first BPA administrator, the agency adopted a policy of a blanket or so-called "postage stamp" rate along the entire transmission system. This was done to encourage widespread development of natural resources and provide communities throughout the region full opportunity for economic development. The agency set the initial uniform wholesale price at $17.50 per kilowatt year--midway between the price based solely on the transmission distance and the blanket rate as identified by the Oregon State Planning Board. The demand for this cheap power grew quickly.[8]

By the fall of 1938, work commenced to finish the powerhouse superstructure for four additional units. Even before their installation, the Corps had initiated in the fall of 1939 excavation and construction to complete the powerhouse by adding the final four units. These last units were rushed to completion in record time, beginning service in December 1943. At Bonneville Dam, and eventually at other Federal dams built in the Northwest, the Corps delivered electricity to the BPA at the converting facilities on the powerhouse. After Congress provided funds in May 1938, the BPA soon had a network of transmission lines radiating from Bonneville Dam. BPA completed its first high tension transmission lines, two 40-mile 230,000 volt circuits between the dam and the Portland metropolitan area, on 1 December 1939. Experiencing rapid wartime expansion, BPA integrated Bonneville power with that produced by other public and private power systems in the Northwest to become the chief supplier of electric power in the region.[9]

Faded patches of camouflage paint still clinging to the Bonneville Auditorium and Administration buildings recall Bonneville Dam project's involvement in the war effort. The Army stationed almost 200 soldiers at Bonneville to protect railroad tracks and bridges in the area. In addition, the Bonneville project had its own guards. The Corps of Engineers posted guards in concrete "pill boxes" at the entrance to the project, by the Auditorium, and on the Washington side of the spillway. Neil Peer, who served as a wartime Bonneville Cuard, later recalled that "there was a 50-caliber machine gun mounted inside the main powerhouse. They kept it trained on the front of the powerhouse door. A number of soldiers walked around inside the powerhouse, while the Coast Guard patrolled the river." The Corps even experimented with smoke screening the project by covering the area with dense clouds of partially burned diesel fuel.[10]

Power demand during World War II used all available capacity; indeed, occasionally the generators worked above their rated capacity. Power generated at Bonneville Dam proved crucial to the World War II military effort. That energy made possible the speedy development of three large aluminum plants in the Portland area, which produced material to fabricate 50,000 warplanes. Electricity from Bonneville also powered the shipyards at Portland and Vancouver, Washington. The yards at Portland turned out a Liberty Ship a day over an extended period. The shipyards in Portland drew on approximately 1,000 ship carpenters who had been trained at Bonneville in the skill of building the forms for the hull-shaped draft tubes. Power from

Bonneville Dam also enabled the Hanford Engineering Works to produce plutonium for atomic bombs. Finally, the navigation lock at Bonneville also aided the war effort. At a time when railroad cars were in short supply, barges carried grain, ammunition, and other essential commodities through the Bonneville lock. Clearly, vital war operations would have been impossible without Bonneville.[11]

Chapter 4: Fish Facilities

The Pacific Northwest is famous for its annual runs of salmon and steelhead trout. The Columbia River watershed historically produced more chinook salmon than any other river system in the world. These anadromous fish, which spawn in fresh water and grow to maturity in salt water, depend on the Columbia River system for their existence. The Corps of Engineers recognized at tbe time of its "308" studies that dams on the Columbia River posed a threat to the fish runs. The North Pacific Division Engineer, Colonel Lukesh, raised the issue with the Chief of Engineers in 1929: "In connection with tentative design of dams . . . it appears that provision should be made for the passage upstream of fish, especially salmon migrating to breeding places." He also accurately foresaw that "such provision may have an important effect upon the cost of the dam and possibly upon the water available for power generation during periods of low flow."[1]

The final 308 report, submitted in 1931, included fishways in its design and cost estimates for each proposed dam. However, fish passage facilities on the scale required for dams of the size proposed had never before been attempted. As the U.S. Commissioner of Fisheries reported to Congress, there had "never before been built, in either America or Europe, a structure of such size that obstructed migratory runs of such magnitude." Writing to Senator Charles McNary, the Commissioner promised "a detailed study of the character of the runs of fish at this point and the engineering features to be encountered in the construction of suitable fishways . . . in order to devise adequate protective works prior to the construction of the dam." Local fishing interests loudly echoed the Commissioner's fears that a dam at Bonneville would prove devastating, since it posed a barrier to the spawning grounds of 75 percent of the migratory fish runs. Under intense lobbying by Oregon fishing groups, Senator McNary pledged to "bend every effort to the end that adequate protection is afforded [the fishing industry]."[2]

Upon adoption of the Bonneville Dam project in September 1933, the Corps of Engineers immediately began work on fish passage facilities. Consulting with the U.S. Bureau of Fisheries, the fish and game commissions of Oregon and Washington, and various regional fishing associations, the Corps assembled a team of fisheries experts to devise a plan for passing migratory fish upstream and fingerlings downstream. Key members of the team included the Bureau of Fisheries aquatic biologist Harlan Holmes and hydraulic engineers Henry Blood and Milo Bell. Working under a compressed timeframe, the experts assembled existing data, conducted further studies, and debated the merits of various proposals with the interested governmental agencies and private fisheries groups. No consensus could be reached on the best type of fishway to use. Most Federal and Washington State fisheries experts favored fish lifts (or locks), but Oregon experts and commercial fishing interests believed that the lifts were too experimental and considered conventional ladders preferable at such an important location as Bonneville. The preliminary design submitted on

1 September 1934--less than a year after the project got underway--called for both lifts and ladders and a novel collection system.[3]

Harlan Holmes later praised the working atmosphere provided by the Corps, recalling that "from the very beginning our relations with the Corps of Engineers was extremely cordial and cooperative." The U.S. Bureau of Fisheries agreed with Holmes, noting that "throughout the study, valuable assistance was rendered by the Corps of Engineers in many details of design of the various structures required." Initially, the Oregon State Fish Commission was less complimentary of the Corps' Bonneville fish passage design. In response to the preliminary proposal, the Commission wrote to Colonel Robins "protesting against the adoption and installation of any untried and unproven device involving theoretical principles at Bonneville, which would in event of failure place the entire salmon run in jeopardy." Colonel Robins assured the Commission "that the War Department is very anxious to arrive at the best possible solution of this question of getting fish over the dam."[4]

Senator McNary, once again heavily involved in Bonneville matters, tried to reassure Oregon fish interests of the Corps' sincerity in finding the best solution to the fish passage problem. During the winter of 1934-35, McNary labored assiduously to bring all the parties into agreement on a fish protection plan. The Corps revised its plans to accommodate most of the Oregon fisheries' concerns, but in so doing increased the costs involved from an estimated $2.8 to $3.6 million. While the compromise plan was $900,000 less than what the Oregon Fisheries Commission proposed, it represented $1.1 million more than the Public Works Administration wanted to appropriate for fish passage facilities. After applying considerable political pressure, McNary extracted a commitment from the Public Works Administration to appropriate $3.2 million--enough to fund the key elements of the compromise plan.[5]

After an acceptable resolution of the Bonneville fisheries problem emerged in the spring of 1935, John Veatch, Chairman of the Oregon State Fish Commission, assured Senator McNary that "we are very well satisfied with the arrangements for the passage of fish at the Bonneville Dam." Veatch added that

> Colonel Robins and his assistants at Portland have been at all times most courteous and have worked with us in every way possible. We certainly have no complaint as to the cooperation of the engineers and our work would have been made a great deal more difficult if the engineers had taken a different attitude toward our various requests.

He concluded by acknowledging McNary's key role in producing a feasible fish passage plan: "Your efforts in our behalf in my opinion have been the chief factor in a satisfactory solution of our problems, have helped smooth the way for the engineers and have made our task much easier." As the Corps incorporated the elements of the fish passage plan into the actual construction of the dam, these featues underwent further modification. The installed system--fish ladders, hydraulic fish lifts, a unique collection system, and bypasses--ultimately cost almost $7 million.[6]

The main feature of the fishways system constructed at Bonneville consisted of three reinforced concrete fish ladders. They resembled a long stairway comprised of pools 16 feet long, 40 feet wide, and 6 feet deep, each 1 foot higher than the last and leading to the 72-foot high pool behind the dam. Originally, the fish ladders contained solid overflow weirs, but the partitions were altered later to include underwater passageways. The submerged openings between the pools and regulated jets of water encourage the fish to swim rather than jump from pool to pool, thereby avoiding injury. The plan required one ladder at each end of the spillway structure and one at the north end of the powerhouse.[7]

The fish lifts, one pair at either end of the spillway dam and another pair at the south end of the powerhouse, operated on the principle of a navigation lock. Designed to accommodate 30,000 fish per day, the lifts were built and operated in pairs and consisted of a vertical hydraulic chamber 20 feet by 30 feet and 105 feet high. To attract fish into the chamber, a small amount of water was admitted and then allowed to flow out through the entrance. Once the fish swam in, the operators closed the chamber and raised the water to the reservoir level. A grillage rose beneath the fish to force them out at the top of the reservoir behind the dam. Initially, Holmes considered the locks superior to the ladders as passage devices, but over time the opposite proved true.

The fish experts realized that the effectiveness of the fishway system depended in large measure on its ability to attract fish. Fishways at other North American dams had never satisfactorily solved this problem. After extensive model studies of the hydraulic features of the devices proposed and thorough analysis of existing data, Holmes recommended a collection system that provided "(1) an expanded or multiple entrance supplied with (2) a volume of water much greater than can be supplied through the fishway proper; [and] (3) the addition of this water in such a manner as to produce a nearly constant water velocity from the base of the fishway proper to the several entrances."[8]

As designed by the fisheries experts, the novel Bonneville Dam collection system consisted of two separate arrangements to serve the ladders and the lifts embedded in both the spillway and powerhouse structures. Across the face of the powerhouse, directly over the draft tube outlets, the engineers built a flume-like passage with openings where fish could enter along its entire length. This channel led to the fishway on the north end and to both the fish lock and navigation lock at the south side of the powerhouse. A series of diffusing chambers in the floor of the passage supplied auxiliary water at a controlled velocity to attract the fish. This augmented the flow of the fishway 10 to 15 times, the equivalent of a fair-sized river.

The spillway section used a different collection system. After considerable experimentation, the fisheries experts placed, in front of each endgate of the dam, passageways extending along the abutment walls from the ladders to the tailrace. At the downstream entrance, they used modified, conventional V-shaped collecting traps to prevent the fish from returning to the tailrace. The spillway collecting system received auxiliary water by the same method as the powerhouse system. An alternative fish passage, a series of long pools, and ladder sections designed chiefly for downstream migrants but available for upstream migrants as well, extended from the mouth of Tanner Creek for a half a mile to the upper pool near the east end of the navigation lock.

The fisheries' experts provided several methods to pass the downstream-migrating fingerlings. At the time, researchers believed that most fingerlings could safely make it through the turbines or the spillway gates when excess water was released. In addition, the engineers provided four special bypasses, three to eight feet wide, at points where the fish were most likely to reach the dam. The bypasses, while similar to the ladders in design, were smaller and the drop between the pools greater.[9]

With the closing of the dam in January 1938, the public, engineers, and biologists anxiously awaited the spring salmon runs to test the $7 million fish collection and passage system. Prior to the dam closure in January 1938, the U.S. Bureau of Fisheries conceded that "there is no way of determining in advance whether or not the fish-protective works will be successful or how much, if any, adverse effects the dam will have upon the fish supply." The Bureau optimistically felt that the system would prove "that every possibility of failure or successful operation has been foreseen and provided for." The installation did not disappoint its designers. The fish readily found their way through the collecting channel and up the ladders to the reservoir behind the dam. Counting stations installed in each ladder served to monitor their operation. During the first 30 years of operation, the system passed one million fish of various species annually.[10]

Construction of the Bonneville Dam project also necessitated considerable redesign and relocation of the large fish hatchery facilities operated by the State of Oregon at Bonneville. Built in 1909 near the mouth of Tanner Creek, the Bonneville hatchery (the largest in the world at the time of its construction) and rearing ponds soon played a major role in the propagation of Pacific Northwest salmon. The facility developed and retained a reputation as a world leader in salmon propagation and management.[11]

The Corps needed hatchery lands to accommodate relocation of the railroad and to provide a new access road to the Bonneville project. In all, the State transferred nearly 10 acres to the Federal Government and during 1935-1936 razed the existing facilities and constructed a new and expanded hatchery complex. The architects designed the buildings and grounds to complement the architectural and landscape style of the adjacent Bonneville reservation. The Corps, for its part, acknowledged the presence of the hatchery in planning the railroad relocation. The simplest and least expensive right-of-way realignment required a 250-foot wide fill through the heart of the hatchery complex. To avoid this, the Corps proposed a 75-foot wide, 900-foot long earth-filled, spandrel arch viaduct. Eventually, the Federal Government acquired the hatchery grounds from the State, while the Oregon Fish Commission continued to operate and maintain the fish propagation facilities and programs.[12]

Success of the Bonneville fish passage system emboldened supporters of the Corps' 308 program for multiple-purpose development to vigorously push for its completion. Between 1938 and 1975, the Corps of Engineers and public and private utility companies erected eight dams on the Columbia and seven on the Snake. The fish passage facilities at Bonneville, supplemented by the results of various studies, served as a model for the passage systems installed at these dams. Over time, it became evident, however, that fish passage structures alone could not cope with the problems created by extensive hydroelectric development in the lower reaches of the two rivers. Studies revealed a 15 percent mortality rate from various injuries for migrating fish at Bonneville and other mainstem dams.[13]

The Corps responded to the fish crisis on the Columbia with several programs. It participated in the Columbia River Fishery Development Program, assuming a major role in the hatchery mitigation effort. The Corps financed enlargement of the main Oregon hatchery at Bonneville and supported various kinds of fishery research into the problems of salmon culture. It focused special attention on the difficulties downstream migrants faced. During their spring journey to the sea, young salmon experienced heavy mortality from three sources: 1) passage of juveniles through the turbines; 2) migration delays through the reservoirs; and 3) gas bubble disease caused by nitrogen supersaturation of river water during periods of heavy spill.[14]

The Corps responded to the critical situation with several strategies. Experimentation led to structural modifications of spillways, including the use of deflectors to reduce nitrogen supersaturation. Fish researchers developed methods to direct the downstream-moving fish away from the turbines by constructing bypass systems using orifices, deflectors, and submersible traveling screens. They provided additional protection by spill at dams without effective bypasses and, where possible, increased river flows to move fish through the reservoirs.

Concern over the potentially high reservoir mortalities of bypassed fish and the great expense of bypass systems led the Corps to start another fish mitigation project in the 1970s. Since 1978, Corps personnel have annually collected juvenile salmon at the uppermost dams on the Snake River and at McNary Dam on the lower Columbia and transported them either by barge or truck around the downstream Columbia River dams to a release point below Bonneville Dam. During the 1986 transport season, the Corps team hauled 13,495,834 juvenile fish under this program. Research continues on refining the bypass and transportation systems. The most recent effort to enhance the survival of noncollected migrating juveniles involves the use of sophisticated electronic tools and sonar devices. With a goal of increasing safe fish passage while reducing losses in hydroelectric producton and revenues, the Corps is testing sonar monitoring to direct spill patterns which stimulate fingerlings to pass through spillways and away from powerhouses.[15]

The Corps has attempted to incorporate much of this fishery research into the fish facilities at the Bonneville second powerhouse. The structure contains fish ladders, a fish collection facility for tagging and monitoring adult fish, and a downstream fingerling bypass system. When ocean bound fingerlings reach the upstream face of the powerhouse, they are intercepted by thirty 28-foot wide by 23-foot long submerged traveling screens mounted in front of the turbine intakes at an incline of 55°. The screens direct the fingerlings into gatewells where they are discharged through 12-inch orifices into a 9-foot wide collection channel extending across the inside of the powerhouse upstream face. The collection channel transports the fingerlings into a discharge conduit with reduced flows of water. The fingerlings are released about 200 feet downstream of the powerhouse. Since the downstream facilities proved less effective than originally envisioned, they are still undergoing refinement. The fish facilities initially amounted to $82 million or about 12 percent of the total project cost.[16]

Since Bonneville Dam became operational in 1938, not only have additional dams been constructed in the Columbia River, but more power units have been installed at most projects. The increase of turbine units has reduced the amount of spill and provided additional peaking capability, passing more water and fish through the powerhouses where the fish risk greater mortality. Mitigation measures have helped reduce the impacts from more intensive management of the hydropower potential of the Columbia, but the cumulative fish mortality from the Columbia and Snake river dams remains high. The tradeoffs in the tug-of-war between the demands of power production and the needs of fish conservation, exemplified in the effort to improve fish passage at the Bonneville second powerhouse, continue challenging the Corps' fishery management program.

Chapter 5: Second Powerhouse and New Navigation Lock

Since the Corps built Bonneville Dam in the 1930s, the Columbia River system has been developed into the largest hydroelectric energy producer in the world. The success of Bonneville and other multi-purpose dams in supplying low-cost electrical power attracted industries and people to the Pacific Northwest. The Pacific Northwest economy still depended largely upon timber and agriculture, but manufacturing became more diversified and service industries grew at a rapid pace. The region's aluminum industry, a product of cheap power and the wartime need to supply the aircraft industry, continued to grow in the post-war era. By 1975, it accounted for 30 percent of United States production, used 30 percent of the power available from BPA, and employed 12,000 workers. Energy-dependent aerospace and high-technology industries also developed during the post-war era. Farmers, too, used increasing quantities of electricity to supply the power needs of expanding irrigated agriculture. Cheap power encouraged the Northwest to indulge in the highest per capita power consumption in the United States. Reflecting this growth and opportunity, the combined population of Oregon and Washington increased by 73.5 percent between 1950 and 1980.

By the early 1960s, the ever-increasing demand for power in the region pointed out the limits of the existing Bonneville project. Based on its projections of regional energy needs, the Bonneville Power Administration requested, in 1965, that the Corps prepare a proposal for an additional powerhouse at Bonneville. The completion of upstream dams in Canada as well as Libby Dam in Montana and Dworshak Dam in Idaho had increased the low water stream flows in the Columbia River. The increased flows, especially during peak releases at the upstream dams such as John Day and The Dalles, exceeded the existing generating capacity at Bonneville, with large volumes going over the spillway. A second powerhouse at Bonneville would capture energy lost through the spillway. The original Bonneville Act authorized additional power generation facilities when required by electrical demand.[1]

By the early 1970s, the Corps proposed a second powerhouse with eight main units and two smaller units, having a generating capacity of 558,000 kw. The need to limit tailwater fluctuations to support fish runs and maintain recreational use of the power determined the power plant capacity. Generating capacity represented the energy equivalent of 2.5 million barrels of oil or enough to meet the yearly power needs of 110,000 Northwest homes. As designed, the project represented a mammoth undertaking. The powerhouse, sited in a newly excavated river channel, measured 985 feet long, 221 feet wide, and 210 feet deep. In all, the structure required 800,000 cubic yards of concrete and 70 million pounds of steel.[2]

After careful study, the engineers again chose the Kaplan adjustable blade propeller type of turbine. Compared to fixed blade turbines, the Kaplan had greater operating flexibility, higher overall efficiency, and improved fish passage capability. Eight of the ten turbines produced 105,000 h.p. at a

52-foot head and two, 20,700 h.p. at a 59-foot head. The main turbines, spaced 92 feet apart, had runner diameters of 330 inches and produced a discharge of 20,000 cubic feet per second. The power units' vertical shaft conventional generators carried a rating of 70,000 kV.[3]

The $245 million prime contract for powerhouse construction, awarded April 1978, constituted the largest contract to that time for a Corps' water resources project. The undertaking entailed a number of engineering challenges. The contractor, a joint venture of S. J. Groves and Sons, Peter Kiewit and Sons, and Granite Construction, had to remove enormous quantities of earth and rock: 8 million cubic yards for the foundation, 2 million for the forebay, and 13 million to form the tailrace. The excavation went 190 feet through debris deposited by a massive 800-year-old mountain slide. The 23 million cubic yards of excavation--enough to cover a football field 2.5 miles deep--were used as fill for the new North Bonneville townsite and additions to Hamilton Island downstream from the new town.

The Corps conducted over 80,000 feet of explorations consisting of test pits, wells, and core borings to determine subsurface conditions at the powerhouse site. The tests revealed a deep porous alluvium layer that allowed flows through it in excess of what a strictly pumping-dewatering system could handle. To keep water out of the newly dug powerhouse site, the Corps studied a number of options before deciding to erect a two-foot wide, one-mile long concrete seepage cutoff wall. Constructed in three segments in a 185-foot deep bentonite slurry trench, the cutoff wall reached elevation 80 on the river side and elevation 30 on the tailrace side. As the contractor gained experience in building the wall, he achieved significant cost reductions. The first segment of the wall cost $38 a square foot, while the third section required only $18 a square foot.

As in construction of the original powerhouse and spillway, the Corps used special concretes in building the second powerhouse. Since the foundation rock under the powerhouse proved susceptible to "slaking" or disintegration, it had to be protected from deterioration soon after being uncovered. The contractor successfully used roller compacted concrete to prevent deterioration of the exposed foundation rock. To provide protective cover for such rock on side slopes and smaller horizontal bench areas, the workers applied a three-inch thick layer of steel fiber reinforced shotcrete.

The design of the powerhouse interior called for leaving selected areas of unpainted concrete exposed to public view, requiring a concrete that yielded a relatively smooth surface, free of excessive cracking and other visible defects. To achieve this goal, the contractor used a mix containing a reduced water content. As a timesaving measure during the conventional grout lift operations, the contractor proposed using shotcrete to embed the intake and tailrace bulkhead guides. Tests indicated that latex modified shotcrete possessed the best durability characteristics while exceeding the compressive strength requirements of the job. Because the latex modified shotcrete required only 24 hours of moist cure before air dry curing, the contractor shaved two weeks from the powerhouse construction schedule.[4]

Since the town of North Bonneville lay directly on the site of the new powerhouse, the Corps became involved in a controversial seven-year effort to relocate the entire community. Initial discussions between the Portland District and the town officials clarified the community's desire to reestablish itself at a new site. The town officials displayed enthusiasm for creating a model community, but such eager optimism soon dissolved as residents became aware of existing limitations in Federal law governing relocation.

Federal resettlement authority, established in the Relocation Assistance Act of 1970, limited the Corps to dealing with individuals, not local governments. This fact stymied the Corps' efforts to accommodate, in any planned manner, the desire of most North Bonneville inhabitants to remain together in a new site. To resolve this impasse, Representative Mike McCormack of Washington secured a provision in the Water Resources Act of 1974 authorizing the Corps to directly assist government officials of North Bonneville in planning a new town, in acting as a real estate broker for lands in the new town, and in building utilities for its residents. Under subsequent agreements, the Corps promised that homeowners and businesses would receive compensation for their property and the opportunity to relocate in the new town at fair market value. The Government also provided rent-free interim housing to those dislocated before lots became available in the new town. Finally, the Government agreed to replace municipal facilities in the new location at no cost to the town. The Corps' relocation effort marked the first expenditure of Federal funds to plan, design, and develop a new community in connection with a water resources project.

From March 1974, when the first public meeting to choose the site for the new North Bonneville was held, to March 1978, when the Corps gave possession to the town, the entire process was filled with disagreement and acrimonious law suits. Throughout the controversy, the people of North Bonneville maintained a different view of the Government's obligations in relocating the town than did the Corps. The Corps had never before assisted in planning the relocation of a town as a whole and narrowly interpreted its legal obligations throughout the undertaking. On the other hand, the townspeople continually expected more financial compensation for the negative impact of the process of powerhouse construction and town relocation than the assistance legislation allowed. The community feared the loss of its long-term cohesion and economic viability. The Corps declared that it was "not authorized to run a chamber of commerce type operation to insure 'viability'." Inspite of disagreements and misunderstanding on both sides, the Portland District successfully completed the $37 million relocation project, and the residents dedicated the new town in July 1978. The ultimate plan included raising the new town site above the 100-year flood plain and installing public utilities, parks, a central business district, and all public buildings for a community of 600 inhabitants--the approximate size of the original town.[5]

A cultural resources survey conducted during the early stages of the powerhouse project identified a significant archeological site, containing evidence in an undisturbed state of a sequence of occupations from prehistoric through historic times. The journals of explorers Lewis and Clark contained references to the Indian settlement. The site, protected under deep fill material placed during the original construction of Bonneville Dam, lay in the middle of the new river channel below the powerhouse. The Corps awarded a $1.2 million contract to recover the cultural materials necessary for site analysis and interpretation. The archeologists retrieved about 1,100 cubic feet of artifacts, ranging from centuries-old stone tools and pottery to metal buttons and whiskey bottles from the mid-1800s.[6]

Other work on the project involved relocating four miles of Washington State Highway 14 and three miles of Burlington Northern's railroad track. The railroad relocation required a 1,400-foot tunnel through unstable ground, while the highway rerouting over the same terrain included three bridges and one underpass beneath the railroad. Total relocation costs came to $32 million. As finished, the project included fish facilities to pass upstream migrant adult anadromous fish and downstream migrant fingerlings. In addition, the new powerhouse contained extensive visitor facilities utilizing a self-guided tour concept. Formal dedication of the second powerhouse occurred on 1 June 1983, with the entire project reaching completion in September 1986 at a cost of $662 million.[7]

While relocation of North Bonneville and the construction of the second powerhouse proceeded, the Corps also investigated the need for a new navigation lock at Bonneville. The existing Bonneville Lock, completed in January 1938, was 76 feet wide and 500 feet long; while the other eight locks on Columbia-Snake Inland Waterway measured 86 feet wide by 675 feet long. As the existing annual Bonneville lock capacity of 13 million tons is reached, congestion delays will increase and the waterway capacity will be constrained. With a standard size facility, the Bonneville lock capacity would increase to 30 tons annually, adequate through the year 2040.

The smaller capacity of the Bonneville lock meant that barge tows made up for all the upstream locks must be broken into smaller units to pass through Bonneville and then reassembled for the upstream passage. This procedure doubled or tripled the time-in-system compared to the larger locks upstream. The new lock would reduce the average time-in-system from 12.7 to 1.9 hours. In addition to inadequate dimensions, the configuration of the Bonneville lock at both approaches presented hazardous conditions to shipping. The proposed size and alignment of the new lock will overcome these problems, providing safe approach conditions for large tows. The estimated construction cost of the new navigation lock project at Bonneville is $200 million, with the work slated for completion in five years (April 1992). As required by the Water Resources Development Act of 1986, 50 percent of the project funding will come from the Inland Waterways Trust Fund.[8]

Bonneville, first and in many ways most significant of the multi-purpose structures built by the Corps across the surging Columbia, introduced innovations in dam design and provided the power which would change the economic future of the Pacific Northwest. Confounding the critics who doubted that Bonneville's vast amount of hydroelectricity would ever be sold, the dam's power proved essential to the war effort and enabled the Northwest to participate in the national postwar economic boom. Bonneville Dam, moreover, accomplished Roosevelt's goal of getting the Federal Government directly into the production of electric power for public and private consumers throughout the Northwest. The electrical energy from Bonneville, in turn, led directly to the creation of a Federal power marketing agency: the Bonneville Power Administration. Both undertakings fulfilled major goals of Roosevelt's New Deal for America.

At the time of its design and construction in the 1930s, the Bonneville Dam project contained many unprecedented features. No other dam in the United States had been designed to withstand floods with flows exceeding 1,000,000 cubic feet per second, as Bonneville had to do. The spillway, as a diversion/overflow structure, required a different design than the other major water impounding structures built during the 1930s, such as Roosevelt, Hoover, Shasta, and Grand Coulee dams. The original spillway design assumed that the stilling basin and baffles would require renewal at 15-year intervals. In fact, the engineers found, based on regular examinations, that both the steel and special cement used in the dam proved remarkably resistant to the effects of high-velocity water and abrasions, suffering only localized zones of erosion. The Corps did not carry out major repairs until 1955, 17 years after completion of the dam. This record justified the original decision to employ a pozzolanic cement--a judgment questioned by some experts at the time.[9]

The Bonneville powerhouse design also called for different treatment than required in other major hydroelectric projects at the time. Bonneville's planned generating capacity could be compared to only a few other hydroelectric installations and even these few operated under different design parameters. The operating "head" or pool height of Hoover, Grand Coulee, and Wilson dams remained constant, while at Bonneville considerable seasonal variation occurred. This situation led to one of the earliest major American uses of the Kaplan turbines. Other significant aspects included the massive cofferdamming effort, the innovative fish passage system, and the installation of the largest single-lift lock to that time.[10]

Planning, designing, and constructing the Bonneville project challenged the engineering and managerial capabilities of the Corps of Engineers. The North Pacific Division Commander, Colonel Thomas Robins, closely supervised the hiring and direction of the key Division and District personnel, as well as outside consultants involved in the project. Robins also played a major role in the controversial political decisions of power marketing, fish passage, and inland navigation.[11]

The public has displayed a keen interest in the Bonneville project since its inception. Hundreds of thousands annually visited during construction to observe the massive operations. This public interest has persisted over time with over 500,000 visiting the dam in 1985. Recognizing the project's role as a major regional tourist attraction, the Corps of Engineers has always operated Bonneville as a public project (except during World War II), encouraging the public to see how their tax dollars are spent. The Corps has developed two project visitor centers, containing fishviewing rooms, interpretive displays of the construction and function of the dam, and exhibits on the natural and human history of the Columbia Gorge. Similarly, the Corps has maintained much of the original character of the project, as seen in the landscaping, powerhouse, spillway, lock, fish hatchery, and administrative buildings. Reflecting the national historical significance of the Bonneville Dam project, the Secretary of the Interior has designated its remaining original elements as a National Historic Landmark. Bonneville Dam continues to fulfill the goals of its planners and builders as it contributes to the regional and national welfare.

Chapter 6: An Historic/Technological Context for the Bonneville Dam

When work on the Bonneville Dam began in the early 1930s, it represented a construction project of almost unprecedented scale in the United States. Despite its size, construction of the Bonneville Dam did not involve any radically new technologies. Some of the work on the project was quite innovative, as exemplified by the use of scale models to help determine potentially destructive erosion patterns along the downstream slope of the spillway. But in general terms, the Corps' work at Bonneville continued or expanded upon previously existing design methodologies and construction techniques. Given the paucity of historical data related to the initial design of the Bonneville Dam and Powerhouse, this analysis provides background material on the technological context within which the Corps of Engineers made their design decisions.[1]

The economic significance of the Bonneville Project primarily stemmed from the huge amounts of hydroelectric power it generated. The ten turbine/generator units in the powerhouse were valuable components of the Bonneville Power Administration's regional power grid. Since the generators operated as a result of the dam raising the level of the Columbia River and allowing the turbines to capture the kinetic energy of falling water, the technological context of the dam/spillway and the powerhouse have been singled out for special attention.

Overflow Dams

Dams played a critical role in the development of many ancient civilizations and are essential to many historic and modern water supply and power systems. The ability to store water and divert it from a stream for use elsewhere can be a very useful technology, especially in arid environments. The development of the earliest large-scale diversion dams on major rivers occurred in Mesopotamia (i.e., present-day Iraq) along the Tigris and Euphrates Rivers and their tributaries. The most impressive of these structures was a dam built by Sennacherib on the Khosr River near Ninevah around 690 B.C. Stretching a length of 750 feet with a maximum height of 9.5 feet, this dam diverted water into a large irrigation canal that nourished otherwise barren desert land.[2]

As a masonry overflow structure, Sennacherib's Khosr River dam was the direct technological ancestor of the Bonneville Dam. Like Bonneville, it raised the level of the river and diverted water for beneficial use. Sennacherib's design also allowed excess flood waters to pass over the dam without destroying its structural integrity. During the next two thousand years, a variety of cultures built overflow dams, but, in terms of technological understanding, they did not represent a substantial advance over techniques employed in ancient Mesopotamia. They were designed on a "cut-and-try" basis with previously successful designs serving as the source for new structures. This reliance on precedent was not necessarily a bad thing; in fact, in the 20th century, the prominent dam engineer Edward Wegmann wrote that "[when designing overflow dams] it is always advisable to compare them with profiles of similar structures which have been standing successfully for a sufficiently long period."[3]

Beginning with a few 18th century Spanish treatises, hydraulic engineers started analyzing the stability of designs using elementary principles of statics.[4] During the 19th century, the gravity dam design process incorporated these theoretical considerations. The Great Stone Dam on the Merrimack River at Lawrence, Massachusetts, represented an early example of an American overflow dam built in accordance with elementary principles of statics.[5] Completed in 1848, this dam provided water power for a huge complex of textile mills. Its designer Charles Storrow went to great lengths insuring the structure would not wash away during heavy floods. After studying European practice, Storrow developed a stone masonry design with a sloping upstream face and a sharply inclined, almost vertical, downstream face. This design utilized a theoretical understanding that the resultant force of the water pressure and the weight of the dam needed to pass through the "middle third" of the foundation. The Lawrence Dam's hard granite foundations enabled the structure to withstand heavy overflowing without eroding. Although a few other American overflow dams possessed vertical downstream faces, foundation conditions at many sites dictated the necessity of developing a different type of masonry overflow dam.[6]

The theoretical impetus for developing such a technology came from the French engineer M. De Sazilly, who first postulated a "rational" profile for masonry gravity dams in the 1850s.[7] De Sazilly's profile formed a triangle with a vertical upstream face and a sloping downstream face. Designs using this profile have proportions with a general height-to-width ratio of 3:2 (e.g. a dam 150 feet high would have a base width of 100 feet). If engineers wished to reduce stresses in a dam using this design methodology, they could increase the width of the structure and thus employ more material. During the late 19th century, many engineers adopted De Sazilly's profile and used it in conjunction with the "middle third" theory to insure structural stability. The technology had two drawbacks: it required large quantities of material and was expensive. However, the cost did not dissuade large, wealthy organizations from constructing dams of this type. Engineers adopted the technology for many large structures such as the Assuan Dam in Egypt (1904) and the New Croton Dam (1907) built as part of New York City's water supply system.[8]

The triangular gravity dam profile initially developed by De Sazilly proved well suited to overflow structures. By smoothing out the dam's top and downstream edge into a continuously curved surface, it became possible to develop designs especially geared towards handling overflow.[9] The shape chosen by most engineers for the downstream face called for a gentle curve that flattened out at the bottom in order to turn the flow "either into a horizontal or slightly inclined upward direction." This shape, referred to as an ogee curve, helped reduce the tendency of the overflow water to erode the foundation at the downstream edge of the dam. This erosion, or scour, can have a devastating effect on a structure's stability. The value of using a curved downstream face to reduce scour became apparent as early as the 1840s when John B. Jervis used it for the spillway of New York City's Old Croton Dam. In the 1890s, the significance of scour became dramatically apparent when the overflow Austin Dam near Austin, Texas, collapsed during a heavy flood. The Austin design was theoretically capable of withstanding the reservoir's hydrostatic pressure, but the heavy overflow weakened the foundations and caused the structure's failure by sliding.

By the early 20th century, numerous stone masonry, overflow gravity dams with curved downstream faces operated in the United States. Engineers soon adopted this technology for concrete dams utilizing the same basic structural shape. A good example of such a structure was the concrete gravity McCalls Ferry Dam in Pennsylvania. Designed by Hugh L. Cooper as part of a hydroelectic power installation and completed in 1911, the McCalls Ferry Dam (now called the Holtwood Dam) set a standard for American overflow dams.[10]

In developing overflow gravity dam technology during the late 19th and early 20th centuries, engineers began equating greater safety with increased thickness. After the failure of the Austin Dam, engineers concluded that the best way to insure against catastrophic collapse required flattening out the downstream slope of the dam. A flatter slope resulted in wider foundations; in turn, this increased width helped insure that the resultant force would act on the "middle third" of the structure's base. The use of a gentler slope also meant that water would flow over the dam with a more horizontal trajectory, thus reducing the likelihood that scour could undermine the foundations.

In considering the character of the Bonneville Dam design, one particular dam/spillway stands out as an important precedent. Although no evidence exists of its use as a direct model for the Bonneville design, the similarity between the two appeared undeniable. That structure was the concrete spillway built as part of the Catun Dam along the Panama Canal. Completed shortly before the canal opened in 1914, this dam played a critical role in impounding the Chagres River for navigational use.[11]

The earthen Gatun Dam was located in a tropical environment subject to intense rainfall. Because permanence was vitally important, the Army Corps of Engineers took special care to design a concrete spillway capable of withstanding heavy overflow. A comparison of this structure's bulky profile with Bonneville indicated both adhered to a design philosophy that placed a premium on massive construction. In addition, both designs utilized concrete "baffles" on the spillway's extreme downstream edge to interrupt the flow of water and help dissipate its energy. Overflow dams of the early twentieth century did not commonly use baffles, and it was significant that both of these designs employed them.

Finally, the Catun and Bonneville dams both used vertical "Stoney" gates to control the reservoir level. These gates allowed the dams to store water at a relatively high elevation; however, during periods of heavy flooding when large quantities of water must be released, these gates could be raised to facilitate increased flow over the spillway. In essence, the gates enabled the dam operators to gain greater control over the water storage level and allowed them to cope safely with heavy floods. Named after its inventor F.G.M. Stoney of Great Britain, the technology of Stoney gates dated to the late 19th century and was used on numerous European and American dams prior to 1910.[12] Stoney's design required the use of vertical gates, usually built of steel, that moved "in vertical grooves in masonry piers." The piers rested on top of the dam proper and contained "trains of rollers" that guided the gates' movement. The gates were counterbalanced with weights to facilitate their handling. When necessary to release water through a spillway controlled by Stoney gates, operators raised the gates, allowing water to flow through the space between the bottom of the gate and the top of the dam's sill. The higher the gate was raised, the more water released. Conversely, to stop flow over the spillway, the gates were dropped to a closed position.

The engineers at Bonneville had a range of technological options for controlling spillway overflow and did not need to undertake basic research on the problem in developing their design. For example, Stoney gates were not the only type of technology used to regulate flow over spillways. Tainter gates also served the same purpose on many American dams by the early 1920s.[13] Usually smaller than Stoney gates, tainter gates were hinged structures located between piers on the top of a spillway. By rotating the gates around the hinges, flow was regulated in a manner similar to that employed by raising and lowering Stoney gates. Stoney gates were best suited for spillways with wide spacing between the piers, and this factor almost certainly precipitated their selection for the Bonneville design. Since engineers widely understood the technology, they easily utilized Stoney gates at Bonneville. A review of overflow dam technology prior to the Bonneville project suggests that engineers attempted little at Bonneville that had not be done elsewhere at an earlier date. The basic engineering concepts dated to ancient times, while the theories supporting the design can be traced to the mid-to-late 19th century. Certainly the scale of the project gave engineers good reason to be extremely careful about the dam's long term stability. As a result, they utilized a conservative design methodology that minimized the risk of failure.

Hydroelectric Power

For thousands of years, mankind had harnessed the kinetic energy of falling water as a source of power. In ancient times, the current of swift flowing rivers turned the blades of undershot waterwheels that, in turn, lifted buckets of water for use on irrigated fields.[14] For many years, users largely confined waterpower to the raising (or pumping) or water or to the milling of grain. During the Middle Ages and the Renaissance, waterpower development centered around the refinement of vertical overshot waterwheels.[15] In contrast to the earlier undershot wheels in which the power depended upon the speed of the water hitting the wheel blade, the overshot wheel developed its power in relation to the weight of the water falling a distance relatively equivalent to the diameter of the wheel. The origins of the Industrial Revolution in 18th century Great Britain and its subsequent transfer to the United States were often associated with the development of steam engines. While steam power comprised a critical factor in fueling the Industrial Revolution, steam hardly accounted for all the increase of power during early industrialization. In fact, waterpower supported many of the largest factory complexes of the 18th and 19th centuries, including the famous textile mills of Lowell, Massachusetts.[16]

As the demand for textiles expanded in the mid-nineteenth century, the businessmen and engineers who owned and operated textile mills strove to increase their productivity. Because of its size and prominence in American industry, Lowell became the focus of the efforts to improve the efficiency of waterpower systems. Once the owners of the Lowell mills diverted the river's entire flow into the city's power canals, the only means of increasing power production (and hence improve the profitability of their investment) lay in improving the efficiency of the waterwheels and power transmission systems. All of the original Lowell mills utilized vertical breastwheels, which was a variation of the overshot wheel. This machinery could achieve efficiencies in the range of 60-70 percent, but, as time went on, the owners became dissatisfield with this performance.[17] A solution to the problem came in a new type of technology for translating waterpower into mechanical motion. Rather than depend upon either the impact of falling water on a wheel or the weight of water falling through a certain distance, the new system utilized the pressure of water under a given head to provide power. These new devices were called turbines.

By the 18th century, industrialists used crude forms of pressurized turbines, referred to as barker's or scotch turbines, but their efficiency often proved no better than standard waterwheels. In the 1820s and 1830s, the French engineer Benoit Fourneyron developed a pressurized turbine that eliminated the inefficiencies of earlier turbines. Known as the Fourneyron turbine, this hydraulic motor developed power as water flowed outward from the turbine casing and caused the rotation of an interior "runner." Under a full load of water, the Fourneyron turbine operated with considerable efficiency. But if the amount of water used to power the turbine dropped even slightly, the efficiency declined dramatically.[18]

After Fourneyron's success in demonstrating the practical possibilities of a pressurized turbine, others experimented with different designs that operated efficiently under a range of water loads. Among the most important of these engineers, James B. Francis had the responsibility for operating the Lowell canal system in the mid-19th century. Francis developed a turbine in which water rotated the runner by flowing into the interior of the design and then exiting out of the bottom. This inward flow turbine used wicket gates to control water entering the turbine to reduce turbulence and help increase overall efficiency. Other engineers soon adopted the basic Francis turbine design, and it became a standard in American mills. During the latter 19th century, engineers refined inward flow turbine design by the addition of draft tubes which carried away water as it exited from the turbines. Like wicket gates, draft tubes reduced turbulence and thus increased efficiency.[19]

At the end of the 19th century, reaction turbine design had reached an advanced stage of development. Many companies sold turbines for general use by a wide range of mills. As part of commercial marketing strategies, turbine firms standardized designs according to the head and amount of flow available at a given site.[20] A mill owner could simply calculate the head and flow at his mill and then order a turbine (or set of turbines) designed to operate at maximum efficiency for this particular set of criteria. The wicket gates allowed efficient operation under a range of water flows, but a given turbine could usually operate satisfactorily under only a small range of heads. Thus, a turbine designed for efficient power production under a head of 30 feet would function much less efficiently under a head of 40 feet. The limitations of turbine efficiencies under varying heads challenged the engineering profession; this is why companies sold a number of designs to meet various conditions. Since most mill sites did not experience a wide variation in head, only one size turbine worked for a particular site. Further development of turbine technology awaited a demand that could profitably benefit from designs adaptable to changes in head. Subsequently, this demand turned out to be associated with the growth of hydroelectric power projects in the early 20th century.

The history of modern electric power systems dates to the early 1880s when Thomas Edison developed his initial direct current (DC) system. Although some arc-lighting systems operated in the 1870s, not until the opening of Edison's Pearl Street Station in New York City in 1882 did a system geared toward incandescent lighting and the powering of small motors prove commercially viable. Edison subsequently franchised his system to many cities in the United States and parts of Europe, prompting other engineers and manufacturing concerns to develop competing systems.[21]

Electrical current was generated by the movement of a conductor, usually a copper wire, through a magnetic field. Rotary motion proved ideally suited to the generation of electric current, and in the early 1880s, electrical generators were connected to water-powered turbines. The original DC systems developed by Edison could not transmit power more than about seven to ten miles without dissipating current. To obviate the limitations of DC systems, engineers developed <u>alternating</u> current (AC) systems which gained wide acceptance by the early 1890s.[22]

High voltage AC technology offered a solution to the problem of long distance transmission, but it suffered from the difficulty of transmitting <u>power</u> (as opposed to light) over a single line of AC current. Whereas a single circuit (or single-phase) of AC current could readily supply electricity for an incandescent lighting system, this circuit could not easily power motors. To overcome this limitation of AC technology, engineers developed a transmission technology that utilized more than one line of current. Such polyphase circuits allowed for power transmission by creating "rotating magnetic fields" used to turn the armature of electric motors.[23]

Regardless of whether part of a single-phase or polyphase system, alternating current oscillated at a wide range of frequencies. Such oscillations of alternating currents were described in terms of how many occur per second. In the 1890s, electrical manufacturing companies developed a variety of different frequencies for commercial use while searching for an optimal standard. By the 1920s, Westinghouse's 60 cycle AC system had become the standard for electric power systems.[24]

The initial development of hydroelectric power did not entail any dramatic changes in water turbine technology. Engineers readily adapted the same reaction turbines that had been developed to produce mechanical power for textile and flour mills to the spinning of electric generators. By the second decade of the 20th century, however, the desire to generate hydroelectric power on large rivers prompted interest in a new type of turbine. The economic impetus for a new turbine came from the fact that existing turbine designs responded to a specific head and a fairly controlled amount of water flow. Engineers dealt with variable waterflow by designing wicket "gates" to control the amount of water entering a turbine and thus help increase efficiency over a range of discharge levels. But the head (or pressure) acting on a reaction turbine could not deviate much away from the design ideal, otherwise the efficiency would drop off dramatically because efficiency was closely related to the angle of runner blades.

With the development of large scale hydroelectric powerplants on major rivers, turbine efficiency took on new meaning. The flow of water in large rivers would vary considerably from spring floods through later summer droughts, dramatically affecting the water level (and hence head) at a hydroelectric power installation. Standard turbine designs provided maximum efficiency for only a small range in head and discharge level. As the amount of water available at the plant varied during the year the turbines could operate efficiently only when the design head and water flow closely matched up with actual hydraulic conditions at the site. At other times, the turbines would operate at reduced efficiency. The solution to this problem lay in developing a turbine in which the angle of the blades could be altered in response to varying hydraulic conditions.

Victor Kaplan, a Czechoslovakian engineer, became the first to successfully develop a turbine with "variable pitch blades" that could operate efficiently under varying conditions.[25] Kaplan developed his turbine concept before World War I, but actual implementation did not occur until 1919 when the first Kaplan turbine became operational in Austria. The Kaplan turbine was designed for low head, high discharge hydroelectric plants, and, in order to insure proper operation, included large draft tubes. As hydraulic historian Norman Smith has pointed out, it "opened up a whole new area of hydroelectric development. On rivers of only nominal fall, but sufficiently large flow, really large horsepowers would now be generated without recourse to high dams or other ways of contriving high heads." During the 1920s, use of the Kaplan turbine proliferated in Europe, but American engineers moved cautiously in adapting the new technology. At this time, European engineers demonstrated a proclivity for more sophisticated technology in a wide range of fields; and use of the Kaplan turbine fit in with this pattern. In fact, American use of the Kaplan turbine did not occur until shortly before construction of the Bonneville project in the 1930s.[26]

Hydroelectric power technology was well established in American practice prior to the approval of the Bonneville project in 1933. In the 1890s, most hydroelectric plants were small, at least in comparison with later installations, and usually utilized water power sites first developed for mechanical power transmission. By the first decade of the 20th century, engineers and financiers recognized a long-term market for electric power justifying new construction of large and expensive hydroelectric generating plants. Some of these, such as the Big Creek and the Feather River systems in California, were high-head facilities located in mountain settings. But other systems developed low-head power on large, slow-moving rivers.[27]

Prior to World War I, the McCalls Ferry Dam on the Susquehanna River in Pennsylvania and the Keokuk Dam on the Mississippi River between Iowa and Illinois represented the largest of the low-head installations. The American engineer, Hugh L. Cooper, designed the two plants and both employed large overflow concrete gravity dams. Both the McCalls Ferry and Keokuk Dams were built expressly for hydroelectric power generation and they were not merely adaptations of systems built originally for mechanical power production.[28]

By the beginning of World War I, the American electric power industry no longer depended upon the use of isolated generating and transmission facilities. In their place, utility companies assembled large regional systems that allowed more efficient use of output from individual power plants. The economies of scale that precipitated the development of large systems relied upon the principle of the "load factor." Any given system must be designed to meet the maximum (or peak) load that can be placed upon it. However, this peak load may only last for a short period of time while the average load on the system is much lower. Consequently, the cost of building facilities to meet the peak load may greatly exceed that necessary to meet the average load. To operate a system efficiently, the average load should match the peak load as closely as possible.

By the time America entered World War I, the electric utility industry had developed sufficient technologies to support the operation of large-scale systems serving hundreds of square miles. America's involvement in the war added new impetus to develop large-scale hydroelectric power plants: the need for munitions and fertilizers. With hostilities threatening to cut off nitrate imports to the United States, the U.S. Congress decided to develop electric power facilities for nitrate production. Congressional action produced the Muscle Shoals, later called Wilson, Dam on the Tennessee River in northern Alabama. Designed by Hugh L. Cooper and built under the direction of the Army Corps of Engineers between 1918 and 1925, the massive concrete overflow gravity dam followed the Keokuk design completed only a few years before.[29]

Since Muscle Shoals Dam remained uncompleted at the end of World War I, the project became the focus of a major controversy concerning the Federal Government's direct involvement in the construction and operation of large-scale hydroelectric plants. Not surprisingly, privately financed utilities adamantly opposed Federal involvement in hydroelectric power development, and their opposition delayed the completion and operation of the Muscle Shoals facility for several years.[30]

In the 1920s, the question of developing huge interregional electric power systems became a topic of great interest to businessmen, politicians, and the general public. On the one hand, private utilities promoted a concept referred to as "Super Power" that would foster the building of huge hydroelectric power plants throughout the United States. These plants would provide the basis for an electric power supply network that would connect together all the region systems in the United States into one huge national system. In contrast to this position, others advocated electric power systems under the direct control of the Federal and state governments.[31]

In political terms, those who supported privately financed control of the electric power industry initially won contral over the growth of America's electric power infrastructure. Both Presidents Calvin Coolidge and Herbert Hoover were staunch opponents of Federal interference (or involvement) in electric power development. Some populist politicians, such as Senator George Norris of Nebraska, argued for more governmental control over America's waterpower resources. But, in general, the ability of large holding companies, such as the New York-based Electric Bond and Share Company (EBASCO), to garner control of numerous regional utilities remained unchecked.[32]

In technological terms, the implementation of a "Super Power" system occurred even without the formal enactment of laws or other forms of authorization. By the mid-1920s, the building blocks for such as system were well underway. Among the most prominent hydroelectric power plants representing this new age in electric power history was the Conowingo Dam on the Susquehanna River in northeastern Maryland. Constructed by the engineering firm of Stone & Webster, the Conowingo Dam allowed the Philadelphia Electric Company to extend its service territory into eastern Pennsylvania and New Jersey. The dam and its associated electric power system required coordination among corporate entities in three states. In turn, this required a sophisticated technological, financial, and political apparatus to oversee its planning, construction, and operation. Although a privately financed "Super Power" system of national scope did not become operational prior to the Great Depression, the necessary technologies and organizational structures existed in installations such as the Conowingo Dam and its associated transmission system.[33]

Innovation and Precedent in the Design Process

Once President Roosevelt became convinced suitable foundations existed to support a dam at Bonneville, the Federal Government authorized the project in September 1933. A major project purpose was to provide immediate employment for hundreds of laborers in the Pacific Northwest. Consequently, the engineers responsible for construction did not have the luxury of leisurely studying the engineer problem *in toto* and then developing a complete design scheme providing for optimal technological solutions. Although some early work, such as the erection of workers' housing, did not have much effect on later technological decisions, engineers soon made decisions having a lasting impact on the overall design.

Engineers responsible for the project acknowledged that the accelerated pace of design and construction had an effect on the character of the work. In one of the few technical articles on Bonneville published in the engineering press, C.I. Grimm (Head Engineer, Office of Division Engineer, North Pacific Division) noted that the "immediate relief of unemployment was a very important consideration" and this prompted the letting of numerous contracts oriented towards fulfilling specific tasks. Grimm considered this patchwork method of letting contracts to be "quite satisfactory from the standpoint of providing early employment and expediting completion of the project, but it complicated the problems of engineering and management." Similarly, in a 1937 presentation on the "Electrical Features of the Bonneville Project," L.E. Kurtichanof reported that "office design and field construction work were initiated practically at the same time." He also admitted the initial uncertainty surrounding the ultimate purpose of the power produced at Bonneville: "The location, size and nature of the load to be served was seemingly thought of but little importance and is not better known today [1937] than it was more than three and one half years ago when actual work in the field was first started."[34]

The design process for the Bonneville Dam and powerhouse is difficult to reconstruct in detail because of the paucity of documentary material--undoubtedly reflecting the intense haste in bringing the huge project under immediate construction. The design of the powerhouse's electrical features came secondary to the hydraulic engineering. As Kurtichanof reported, "gradually, the shaping of plans for the powerhouse structure took place but with hydraulic considerations dominating to an extent which all but ignored the need for the accommodation of associated electrical equipment." In the midst of this seeming chaos, the electrical engineering staff studied "numerous schemes of operation...in [an] effort to find one which would best fit into the government's policy when adopted." Since no immediate demand or load existed to absorb Bonneville's power, engineers designed the plant to accommodate either the growth of intense industry in the Bonneville/Cascade Locks area or to feed into a much larger regional system. The electrical system delivered from the generators at 13,800 volts, a voltage low enough to facilitate easy usage at sites located in close proximity to the powerhouse. For long-distance transmission, the transformers raised the voltage to 115,000 volts, sufficient to insure economical transmission of power over hundreds of miles.

The other electrical aspects of the Bonneville output were standard to American industry and not developed in response to any specific particularities of the site. The use of three-phase, 60 cycle current was not extraordinary in any way. In situating the transformers and switching equipment, the engineers at Bonneville chose locations readily accessible in order to facilitate maintenance and repair. They placed the transformers at the front of the powerhouse, just above the gates that controlled flow into the turbines. The transformers were isolated from one another in separate enclosures to prevent "serious trouble in one transformer [from] being communicated to the adjacent one." The engineers located the switching gear on the top of the powerhouse because, as Kurtichanof noted, "the inconvenience of [a] suitable site at ground level for a switching station and the relative high cost of developing one for the initial installation..." This was not the first time switching gear had been placed on the roof of a large powerhouse, as Conowingo Dam used this configuration in the mid-1920s.[35]

Given the uncertainty that surrounded planning for electrical output from Bonneville, it was understandable little material appeared in the engineering press concerning this aspect of the design process. Surprisingly, the use of Kaplan turbines also received little attention. Bonneville represented one of the first American installations employing Kaplan turbines, and, although the technology had found considerable use in Europe in the 1920s, the novelty of the Kaplan turbine in American practice should have prompted considerable discussion about how Bonneville's engineers selected the design. Of course, the wide fluctuation of flow in the Columbia River, even more pronounced before the construction of numerous upstream storage dams, proved ideally suited to the Kaplan turbine. In this context, the decision to install turbines with variable pitched blades represented a logical step in utilizing the maximum power potential of the lower Columbia River. Perhaps a better question for future historical research was not why Kaplan turbines were used at Bonneville, but why more large American hydroelectric plants of the 1920s had not previously utilized the technology.[36]

Although only sketchy data on the design process for the dam/spillway survived, the basic concept was clear. The dam served as a huge overflow structure with features such as a vertical upstream face, a sloping curved downstream face, and vertical Stoney gates. These features did not represent any special innovations on the part of Bonneville's engineers. In fact, the key to Bonneville Dam design was its reliance on proven technology. Since it comprised the focus of a major work relief effort, little incentive existed to conserve or limit the amount of concrete in the dam.

No one engineer had responsibility for the Bonneville Dam design, although H.G. Gerdes of the Corps' engineering staff supervised construction of the dam/spillway structure. The Corps depended upon a consulting board of engineers for technical expertise, with the dam/spillway design largely a product of consensus between military personnel and these civilian engineering consultants. D.C. Henny, a nationally renowned hydraulic engineer and long time resident of Portland, probably played a critical role in developing the final dam design. Henny served as a prominent member of the Bonneville consulting board but died in 1935 after finalization of the dam/spillway design. His untimely death may explain why a detailed description of the Bonneville Dam design process never appeared in print.[37]

In the 26 years prior to this death, Henny participated extensively in the activities of the American Society of Civil Engineers (ASCE) and published numerous articles in the organization's Transactions. He served as Chairman of the ASCE's Special Committee on Irrigation Hydraulics and was a prominent member of the engineering boards established to develop and review plans for the Owhyee Dam in eastern Oregon and the Hoover Dam on the Colorado River. The Bureau of Reclamation built both of these structures, and they stand as major milestones in Western dam history; the Owhyee Dam (completed in 1931) is listed on the National Register of Historic Places and the Hoover Dam (completed in 1935) is a National Historic Landmark. Both were massive concrete gravity structures that reflected the type of design Henny found most appealing.[38]

In advising the Corps on what type of design to employ for the Bonneville Dam, Henny clearly approached the problem from a perspective that held massive gravity designs in high esteem. But beyond this, the relatively tenuous condition of bedrock at the Bonneville site would also have spurred interest in building a dam with an extremely wide base. Increasing the base width of a gravity design reduced the unit loading on any particular part of the foundation and thus helped limit overall compressive stresses. At Bonneville, the danger existed that heavy floods flowing over the dam/spillway would precipitate erosion, or scour, along the foundation, disastrously undermining the structure.

Beyond Henny's structural reasons for advocating materially intensive designs, the bulky dimensions of the Bonneville Dam also helped meet other economic objectives of the project. Technologically, it may have been feasible to develop more materially conservant designs of equal safety, such as flat-slab or multiple-arch buttress dams. But in light of Roosevelt's efforts to bolster the American economy through public works investment, such designs were not necessarily desirable. Massive gravity designs required huge amounts of cement, gravel, sand, and labor to erect. Along with using large quantities of material, which can keep businessmen and suppliers happy, gravity dams require relatively unskilled workers and this feature made them ideal for work relief projects.

While engineering precedent guided the development of the Bonneville dam design, the Corps of Engineers remained receptive to innovative techniques in certain areas. For example, scale model hydraulic testing played a significant role in verifying the value of baffles on the downstream edge of the dam.[39] These baffles helped dissipate the kinetic energy of the water after it flowed over the dam, and they provided protection against scouring action that could erode the foundations and precipitate collapse. Engineers appreciated the utility of baffles before construction of the Bonneville Dam began (e.g. they were included in the spillway of the Panama Canal's Gatun Dam). But the model tests at Bonneville experimentally confirmed the ability of baffles to reduce scour. The tests proved significant in giving the Bonneville engineers confidence in the structural suitability of the final design, and they helped increase public confidence in the safety of the dam.

Along with innovative model testing of the dam/spillway design, Bonneville engineers also performed significant laboratory testing to determine the type of concrete most suitable for construction. Because of the huge quantities of concrete used in the massive gravity design, the Corps was especially concerned that the concrete mixture not exhibit any tendency to crack excessively or disintegrate. As a result of extensive testing in laboratories at the University of California - Berkeley, Bonneville engineers eventually opted to use a new and relatively innovative type of "portland puzzolan" cement.

Raymond Davis, the engineer responsible for overseeing development of this cement, reported in 1938 that interest in the subject came up "during construction of the Bonneville powerhouse in 1934, [when] it was observed that cracks of considerable magnitude and frequency appeared in the heavy walls when the concrete was but a few days old." According to Davis, the powerhouse concrete also exhibited a decided "lack of homogeneity and watertightness." These conditions disturbed the engineers at Bonneville because the dam's long term stability could easily be undermined by cracking and/or excessive porosity if built using concrete of similar quality. Because they considered it "essential that the concrete of the spillway dam should...exhibit a minimum of cracking and a maximum of watertightness," this subsequently led to "a rather extensive investigation of cements and concretes."[40]

Davis and his assistants tested a variety of cements to determine properties such as workability, the tendency of aggregates to separate, the heat of hydration, early-age strength, ultimate strength, permeability, and tensile strength. On the basis of these tests, and estimates that it would be cheaper than "a modified or a low-heat portland cement," Davis reported that "portland-puzzolan cement was adopted as the type for use in construction of the Bonneville spillway dam." The latter mixture had been used previously in the foundations of the Golden Gate and San Francisco-Oakland Bay Bridges, so it was a proven technology.[41]

Extensive testing and cost analysis ultimately led to the selection of a portland-puzzolan cement as the binding agent for concrete in the Bonneville Dam. However, the massive gravity design previously chosen for the dam/spillway should be credited for precipitating interest in developing a special type of concrete. The Corps did not set out to utilize an innovative type of concrete and then adapt the design to the special properties of the structural material. As with the use of baffles, the Corps employed extensive testing to help them in building the dam, but only after the basic parameters of the gravity design had already been settled upon.

In assessing the origins of the Bonneville Dam and Powerhouse and earlier hydraulic designs that preceded it, the Bonneville Project clearly does not represent a form of radical technological development. Certainly, Corps engineers and their civilian consultants faced hydraulic conditions on the lower Columbia River unprecedented in American practice. In addition, the foundation conditions at Bonneville posed unique, site-specific problems. But the technological components used for the project as a whole were not unusual or unprecedented. These components drew heavily upon existing practice and all fit into the mainstream of conservative engineering design. The Bonneville engineers faced non-engineering factors which undoubtedly limited their ability to employ innovative techniques. The magnitude of the job and the hasty schedule imposed by the political requirements of the New Deal practically imposed on them a conservative design based closely upon earlier systems and structures. The long term successful operation of the Bonneville Project testified to both the credibility and suitability of the designs developed by the Corps at Bonneville more than 50 years ago.

FOOTNOTES

Chapter 1

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6. Ibid., p. 21.
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12. Ibid., pp. 3-26; "Civil Works Lesson," pp. 5-9; "Progress Report, Bonneville Power-Navigation Project Federal Works Project No. 28, October 1933 to October 1934" (hereafter, "Progress Report"), PDRHC, pp. 7-10; Ira Williams, "Preliminary Geologic Report on a Series of Prospective Dam Sites on the Lower Columbia River," Aug. 1932, PDRHC, pp. 3-52; Edwin T. Hodge, "Report of Dam Sites on Lower Columbia River," Sept. 1932, PDRHC, pp. 1-81; C.P. Holdredge, "Final Ceological Report on the Bonneville Project, 1937," Jan. 1937, PDRHC, pp. 1-39; U.S. Army, Corps of Engineers, "Bonneville Dam Project: History of Geological Exploration," Portland, OR, 1937, PDRHC.

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Chapter 2

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23. Annual Reports, 1935, Part 1, pp. 1459, 1512; Annual Reports, 1938, Part 1, p. 1828; Annual Reports, 1941, Part 1, p. 1859.
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25. U.S. Army, Corps of Engineers, "Bonneville Dam Project: Construction of Permanent Quarters," Portland, OR, 1936, PDRHC; ibid., "Permanent Roads and Landscaping," ibid.; ibid., "Auditorium and Administration Buildings," ibid.; ibid., "Walks, Curbs, Cutters, etc.," ibid.; Bostwick, Bonneville Project, pp. 27-28; Corps of Engineers, Improvement at Bonneville, p. 22; Portland, Bonneville Dam Record, 16 Feb. 1934, p. 11, 18 May 1934, p. 1, 15 Nov. 1934, pp. 1, 5, 15 Dec. 1934, p. 17, 15 Jan. 1935, p. 5.
26. Cen. Pillsbury to McNary, 22 June 1934, McNary Papers, Box 33; U.S. Army, Corps of Engineers, "Bonneville Dam Project: Community Center," PDRHC; ibid., "U.S. Guards," ibid.; Portland, Bonneville Dam Record, 31 Jan. 1934, p. 6, 27 June 1934, p. 1, 15 Aug. 1934, p. 3, 31 Aug. 1934, p. 2, 31 Oct. 1934, p. 5, 15 Dec. 1934, p. 5; Bostwick, Bonneville Project, pp. 26-27.
27. Annual Reports, 1938, Part 1, pp. 1830-1831; Portland, Oregonian, 29 Sept. 1937.
28. Annual Reports, 1938, Part 1, pp. 1830-1831; Annual Reports, 1939, Part 1, pp. 2003-2004, Portland, Sunday Oregonian, 10 July 1938.
29. J.D. Ross to Pres. Roosevelt, 31 May 1938, NARG 77, RCE, Columbia River, File No. 7249; Jim Marshall, "Dam of Doubt," Colliers, 19 June 1937, pp. 19, 82-84.

Chapter 3

1. Norwood, Columbia River Power, pp. 55-93; MacColl, Crowth of a City, pp. 555-558; Lowitt, The New Deal and the West, pp. 160-163, 170-171, 227; Dodds, The American Northwest, pp. 228-230; W.D. Dodson to Charles McNary, 6, 16 Dec. 1933, McNary Papers, Box 33; McNary to Dodson, 7 Dec. 1933, ibid.; Gen. Pillsbury to McNary, 11 June 1937, ibid.; Portland, Bonneville Dam Record, 9 Dec. 1933, p. 10, 31 Jan. 1934, p. 12, 16 Jan. 1934, p. 3, 16 Mar. 1934, pp. 3, 12, 31 Oct. 1934, p. 2, 15 Nov. 1934, p. 1, 15 Dec. 1934, p. 9, 31 Dec. 1934, p. 8.
2. State Planning Board, A Study of the Wholesale Cost of Bonneville Power (Salem, OR, 1935), pp. 3-22; Portland, Bonneville Dam Record, 15 Dec. 1934, p. 20, 31 Jan. 1934, p. 8.

3. State Planning Board, Use of Electricity in Oregon with Forecasts of Future Demands (Salem, OR, 1936), pp. 7-48; State Planning Board, Recommended Policies for Sale of Bonneville Power (Salem, OR, 1936), p. 8.
4. State Planning Board, Recommended Policies, pp. 1-20; Portland, Bonneville Dam Record, 16 Mar. 1934, p. 12, 18 May 1934, p. 8.
5. Charles Martin to Pres. Roosevelt, 29 Apr. 1935, McNary Papers, Box 33; Martin to McNary, 30 Apr. 1935, ibid.; McNary to W.D. Dodson, 7 Dec. 1933, ibid.; McNary to William Woodward, 27 Feb. 1935, ibid.; Port of Portland to McNary, 30 Apr. 1935, ibid.; Dodson to McNary, 7 May 1935, ibid.; McNary to Martin, 8, 9 May 1935, ibid.; McNary to J.E. Lewton, 11 June 1935, ibid.; McNary to Ben Osborne, 21 June 1935, ibid.; McNary to William Richards, 7 Aug. 1935, ibid.; Martin to McNary, 8 May 1936, ibid., Box 34.
6. Neal, McNary, p. 222; Norwood, Columbia River Power, pp. 55-93; Lowitt, The New Deal and the West, pp. 160-163, 170-171.
7. Ibid.; District Engineer, United States Engineer Office, Portland, Oregon, and Bonneville Power Administrator, The Bonneville Project (Washington, D.C., 1941), pp. 3, 14-20.
8. Ibid.
9. Ibid.
10. Doug Soleida, "Bonneville: The War Years and Beyond," Corps'pondent, Apr.-May 1987, pp. 10-12.
11. "Civil Works Lesson," pp. 4, 21, 29; Marc Reisner, Cadillac Desert (New York, 1986), pp. 168-170.

Chapter 4

1. Col. Lukesh to Chief of Engineers, 8 Mar. 1929, NARG 77, RCE, Columbia River, File No. 7249. Some critics claim the Corps only belatedly recognized the danger Columbia River dams posed to migratory fish runs and only half-heartedly responded to the problem. See, for example, Anthony Netboy, The Columbia River Salmon and Steelhead Trout: Their Fight for Survival (Seattle, 1980), pp. 72-102, 145-147; Oral Bullard, Crisis on the Columbia (Portland, OR, 1968), pp. 45-46, 99-120.
2. U.S. Cong., House Doc., No. 103, 73d Cong., 1st sess., pp. 10, 1539, 1597, 1599, 1602; Kuentz, "The Lower Columbia River Project," pp. 44; Portland, Oregonian, 1 Jan. 1934, p. 2; U.S. Cong., Senate Doc., No. 87, 75th Cong. 1st sess., pp. 2, 28; Commissioner of Fisheries to Charles McNary, 9 Nov. 1933, McNary Papers, Box 33; Hugh Mitchell to McNary, 2 Aug. 1933, ibid.; quote, McNary to Mitchell, 12 Aug. 1933, ibid.; W.L. Thompson to McNary, 25 Aug. 1933, ibid.; McNary to Thompson, 28 Aug. 1933, ibid.; Frank Bell to McNary, 6 Oct. 1933, ibid.
3. "Progress Report," pp. 22-24; Commissioner of Fisheries to Charles McNary, 9 Nov. 1933, McNary Papers, Box 33; Fish Commission of the State of Oregon to Col. Thomas Robins, 5 Sept. 1934, ibid.; Fish Commission to McNary, 22 Aug. 1934, ibid.; Bostwick, Bonneville Project, pp. 25-26; Portland, Bonneville Dam Record, 28 Feb. 1934, p. 9, 11 July 1934, p. 7, 31 Aug. 1934, pp. 4-5.
4. Harlan Holmes to Anthony Netboy, 19 June 1971, copy from Public Affairs Office, Portland District, Corps of Engineers; U.S. Cong., Senate Doc., No. 87, 75th Cong., 1st sess., pp. 29-39, quote p. 29; Fish Commission of the State of Oregon to Col. Thomas Robins, 5 Sept. 1934, McNary Papers, Box 33; Report, "Public Hearings on Adequate Fishways at Bonneville Dam," Portland District, Corps of Engineers, McNary Papers, Box 33, quote on p. 98; Holmes, in a letter to W.D.B. Dodson of the Portland Chamber of Commerce, summed up

the commitment to save the migratory fish runs: "I should not hesitate to state that there can be no basis for any public opinion to the effect that there is a deliberate and thoughtless destruction of the Columbia River salmon industry. All interested State and Federal departments are aware of the importance of the problem and conscientiously endeavored to provide what they consider to be proper and adequate means of fish protection." 13 Nov. 1935, McNary Papers, Box 34.

5. Charles McNary to John Veatch, 14 Sept. 1934, 7 Jan. 1935, 1 Feb. 1935, 6 Mar. 1935, 12 Mar. 1935, McNary Papers, Box 34; Veatch to McNary, 22 Sept. 1934, 2 Feb. 1935, 12 Mar. 1935, ibid.; Hugh Mitchell to McNary, 4 Oct. 1934, ibid.; Astoria Chamber of Commerce to McNary, 24 Nov. 1934, ibid.; Oregon State Game Commission to McNary, 21 Dec. 1934, ibid.; McNary to Ralph Cowgill, 27 Dec. 1934, 21 Feb. 1935, 6 Mar. 1935, 12 Mar. 1935, ibid.; Cowgill to McNary, 19 Feb. 1935, 12 Mar. 1935, ibid.; Gen. Markham to McNary, 10 Jan. 1935, 2 Feb. 1935, 19 Feb. 1935, 27 Feb. 1935, 22 May 1935, ibid.; McNary to Markham, 21 Feb. 1935, ibid.; Portland, Bonneville Dam Record, 15 Dec. 1934, p. 2, 31 Dec. 1934, p. 3, 31 Jan. 1935, p. 5, 15 Feb. 1935, pp. 1, 7, 8, 15 Mar. 1935, pp. 1, 8.

6. John Veatch to Charles McNary, 6 June 1935, Charles McNary Papers, Box 34; Fish Commission to McNary, 22 Mar. 1935, ibid.

7. The following description of facilities is based on Gorlinski, "The Bonneville Dam," p. 213; U.S. Cong., Senate Doc., No. 87, 75th Cong., 1st sess., pp. 29-43; Corps of Engineers, Improvement of the Columbia River, pp. 18-20; U.S. Army, Corps of Engineers, Power, Navigation and Fish Facilities on the Columbia River at Bonneville Dam (Portland, OR, 1948), pp. 18-22; Netboy, Columbia River Salmon, pp. 76-78; Harlan Holmes, "The Passage of Fish at Bonneville Dam," Department of Research, Oregon Fish Commission, Contribution No. 2 (1940), pp. 182-186; "Fishways at Bonneville," Engineering News-Record, 116 (13 Feb. 1936), pp. 236-238; Frank T. Bell, "Guarding the Columbia's Silver Horde," Nature Magazine, 29 (Jan. 1939), pp. 43-47.

8. U.S. Cong., Senate Doc., No. 87, 75th Cong., 1st sess., p. 30.

9. Corps of Engineers, Power, Navigation and Fish Facilities, pp. 21-22.

10. U.S. Cong., Senate Doc., No. 87, 75th Cong., 1st sess., p. 43; Holmes, "The Passage of Fish," p. 186; Annual Reports, 1938, Part 1, p. 1831; Netboy, Columbia River Salmon, pp. 77-78. See also, U.S. Dept. of Interior, Memorandum for the Press: Bonneville Project, 19 June 1938, McNary Papers, Box 37.

11. Stephen Beckham, The Bonneville Hatchery: A Historical Assessment for the Bonneville Navigation Lock Project, Bonneville, Oregon (Eugene, OR, 1986), pp. 1-35.

12. Ibid., pp. 27-33; U.S. Army, Corps of Engineers, "Bonneville Dam Project: History of Railroad and Highway Department," Portland, OR, 1936, PDRHC; Portland, Bonneville Dam Record, 31 Oct. 1934, p. 5.

13. Ed Chaney and L. Edward Perry, Columbia Basin Salmon and Steelhead Analysis: Summary Report, September 1, 1976 (Portland, OR, 1976), pp. 6-7; Northwest Power Planning Council, Compilation of Information on Salmon and Steelhead Losses in the Columbia River Basin (Portland, OR, 1986), pp. 76-95, 128-158.

14. Willingham, Army Engineers and the Development of Oregon, pp. 197-202; Northwest Power Planning Council, Compilation on Salmon and Steelhead Losses, pp. 213, 224-225.

15. Charles Koski, et al., Fish Transportation Oversight Team Annual Report - FY 1986, Transport Operations on the Snake and Columbia Rivers (Portland, OR,

1987), pp. 2-60; R. Gregory Nokes, "Salmon Run Recovers after 50-year Upriver Fight," Portland, Oregonian, 14 June 1987, pp. 1, C6.
16. U.S. Army, Corps of Engineers, Bonneville Second Powerhouse (Portland, OR, 1984), p. 5; U.S. Army, Corps of Engineers, 2nd Powerhouse Fish Facilities Design Memorandum No. 9 (Portland, OR, 1974); ibid., Supplement No. 5 (Portland, OR, 1980).

Chapter 5

1. Willingham, Army Engineers and the Development of Oregon, pp. 220-221.
2. Corps of Engineers, Bonneville Second Powerhouse, p. 8.
3. Ibid., U.S. Army, Corps of Engineers, 2nd Powerhouse Preliminary Design Report No. 11 (Portland, OR, 1975); ibid., 2nd Powerhouse Ceneral Design Memorandum No. 4 Supplement No. 3 Turbine Study (Portland, OR, 1974-1975); ibid., Ceneral Design Memorandum No. 4 (Portland, OR, 1972).
4. Corps of Engineers, Bonneville Second Powerhouse, pp. 3-5.
5. Ibid., p. 4; Willingham, Army Engineers and the Development of Oregon, pp. 221-223.
6. Rick Minor, et al., An Overview of Investigation at 45SA11: Archaeology in the Columbia River Corge (Eugene, OR, 1986).
7. Corps of Engineers, Bonneville Second Powerhouse, pp. 5-6.
8. U.S. Army, Corps of Engineers, "Information Paper: Bonneville Navigation Lock" (Portland, OR, 3 Mar. 1987).
9. C.C. Calbraith and R.R. Clark, "Bonneville Dam Concrete after Six Years," Engineering News-Record (8 Mar. 1945), pp. 121-124; R.R. Clark, "Effects of High-Velocity Water on Bonneville Dam Concrete," Journal of the American Concrete Institute (June 1950), pp. 821-839; ibid., "Bonneville Dam Stilling Basin Repaired after 17 Years Service," Journal of the American Concrete Institute (Apr. 1956), pp. 822-837.
10. Donald Jackson to William Willingham, 23 Apr. 1987, personal communication.
11. Oregon, Daily Journal, 1 Aug. 1934; Portland, Bonneville Dam Record, 11 July 1934, p. 6, 31 Oct. 1934, p. 8, 15 Nov. 1934, pp. 1, 5; Ceorge Sandy to Charles McNary, 15 July 1933, McNary Papers, Box 33.

Chapter 6

1. A good description of the hydraulic models used by the Corps of Enginners in planning the Bonneville Project can be found in J.C. Stevens, "Models Cut Costs and Speed Construction," Civil Engineering 6 (Oct. 1936), pp. 674-677.
2. See Norman Smith, A History of Dams (Secaucus, New Jersey, 1972), pp. 9-12 for description of Sennacherib's irrigation developments in Mesopotamia.
3. Edward Wegmann, The Design and Construction of Dams (New York, 1927), p. 492.
4. Smith, A History of Dams, pp. 192-194.
5. Peter Molloy, "Nineteenth Century Hydropower: Design and Construction of Lawrence Dam, 1845-1848," Winterthur Portfolio 15 (Winter 1980), pp. 315-343.
6. In his article, Molloy provides a drawing of the late 19th century Housatonic Dam on the Housatonic River in Western Mass. that shows a vertical downstream face.
7. For a good discussion of De Sazilly's accomplishments see Smith, A History of Dams, pp. 195-198.
8. Major late 19th and early 20th century masonry gravity dams utilizing a basic "profile of equal resistance" are the Vyrnwy Dam near Liverpool, England

(1890), the Wachusett Dam near Boston (1905), and the Croton Dam near New York City (1907). These are described in Wegmann, Design and Construction of Dams, pp. 82-89, 185-194, 162-184.
9. For a good discussion of the basic principles of overflow gravity dam design, see Wegmann, Design and Construction of Dams, pp. 401-406. Unless otherwise noted, data on overflow dam design is taken from this source.
10. The McCalls Ferry Dam is described in James D. Schuyler, Reservoirs for Irrigation, Water-power, and Domestic Water Supply (New York, 1909), pp. 332-334.
11. Wegmann, Design and Construction of Dams, pp. 589-600, provides considerable data on the Gatun Dam.
12. For extensive discussion of Stoney gates, see Wegmann, Design and Construction of Dams, pp. 351-358.
13. For discussion of tainter gate technology, see Wegmann, Design and Construction of Dams, pp. 418-419. Tainter gates cannot be built as wide as Stoney gates and are not used for large spillway openings. For this reason, they would not have been suitable for the Bonneville site.
14. For a description of the "current-driven noria," see Norman Smith, Man and Water (New York, 1975), pp. 12-14.
15. Terry Reynolds, Stronger Than A Hundred Men: A History of the Vertical Water Wheel (Baltimore, 1983). Reynolds examines in detail the use of vertical water wheels from Roman times through the early 20th century.
16. The importance of water power in the American Industrial Revolution is documented in Louis Hunter, Waterpower: A History of Industrial Power in the United States 1790-1930 (Charlottesville, VA., 1979).
17. The maximum amount of hydropower depended upon the amount of water (measured in cubic feet) and the distance that it fell (the hydraulic drop or "head"). See Reynolds, Stronger Than A Hundred Men, pp. 248-256, for a discussion of water wheel efficiency in the 19th century.
18. Smith, Man and Water, pp. 161-188, provides a good discussion of early turbine development in Europe and America.
19. Smith, Man and Water, pp. 178-182, describes the work of James B. Francis, Uriah Boyden, Samuel B. Howd, and others. Another good source on the history of turbine development in America is Arthur T. Safford and Edward Pierce Hamilton, "The American Mixed-Flow Turbine and Its Setting," Transactions of the American Society of Civil Engineers 86 (1923), pp. 1237-1356.
20. For example, see trade catalogs such as the "New Pamphlet of the James Leffel Water Wheels, Standards, Specials and Samsons," (published by James Leffel & Co., Springfield, Ohio, 1900); "The 'Hercules' Turbine," (published by the Holyoke Machine Co., Holyoke, Mass., 1885); and "Descriptive Catalogue of Alcott's High Duty Turbine," (published by T.C. Alcott & Son, Mount Holly, New Jersey, circa 1890).
21. A comprehensive treatment of Edison's accomplishments in electric power technology is given in Thomas Hughes, Networks of Power: Electrification in Western Society, 1880-1930 (Baltimore, 1983), pp. 18-46.
22. Hughes, Networks of Power, pp. 106-139, describes how direct current systems eventually gave way to alternating current systems despite Edison's opposition.
23. The difficulties of operating single phase AC motors are noted in P.N. Nunn, "Pioneer Work in High Tension Electric Power Transmission: The Operation of the Telluride Power Company," Cassier's Magazine 27 (Jan. 1905), pp. 171-200. The Telluride system became operational in the early 1890s and supplied power to several mining companies in the Telluride district of

southwestern Colorado. By the later 1890s, its single phase technology had been replaced by a polyphase system.

24. See Hughes, Networks of Power, pp. 128-129, for discussion of how a 60 cycle frequency came to be the standard for American electric power systems.

25. Smith, Man and Water, pp. 191-193. All material on Kaplan and his turbine design is taken from this source.

26. Smith, Man and Water, p. 194; in his book, The Tower and the Bridge (New York, 1983), Professor David Billington of Princeton analyzes the work of many structural engineers of the 20th century within the context of a concept he calls "structural art." Billington has praise for the efforts of several American engineers; most of these, including suspension bridge designer Othmarr Amman, were trained in Europe. Billington perceives a definite tendencey for European engineers to base their work on a more mathematically rigorous design methodology. Apparently, the Safe Harbor Hydroelectric Plant on the Susquehanna River in Pennsylvania was the first American facility to feature the technology. This plant ws completed in 1931.

27. It was not always the case that early hydroelecric plants were based upon existing hydraulic power developments. However, the author is not aware of any large storage dams that were built expressly for use in a hydroelectric power system prior to the 20th century.

28. Hugh L. Cooper was an extremely active engineer who played an important role in many of America's most important early 20th century hydroelectric plants. In the early 1930s, he also took charge of designing the Dnieper hydroelectric installation for the Soviet government. A succinct review of his life's work is given in "Hugh Cooper Dies," Engineering News-Record 119 (July 1, 1937), pp. 6-7. A description of the Dnieper project is given in "American Methods Win Fight to Control Russian River," Engineering-News Record 108 (June 23, 1932). This installation was subsequently demolished during World War II to prevent the Nazis from using its power.

29. Cooper publicized his firm's involvement with the Muscle Shoals project in a forty page pamphlet entitled, "Electric Power from the Tennessee River," (published by Hugh L. Cooper & Co., New York, 1924).

30. See Preston J. Hubbard, Origins of the TVA: The Muscle Shoals Controversy, 1920-1932, (New York, 1961), for an extended analysis of the political battles fought over the Muscle Shoals Dam and the role of the dam in the initial formation of the Tennessee Valley Authority in the early 1930s.

31. Guy Tripp, Super Power as an Aid to Progress, (Pittsburgh, 1924); see Hughes, Networks to Power, pp. 297-313, for a description of Pinchot's Giant Power plan for Pennsylvania.

32. In her book Phil Swing and Boulder Dam (Berkeley, 1971), Beverly Moeller is adamant (p. x) in stressing that Hoover actively worked to block Federal involvement in the construction of Boulder (later Hoover) Dam because he favored control of the project by private utilities.

33. An extensive description of the technological and organizational structure that supported development of the Conowingo Dam and its associated transmission system is given in Hughes, Networks of Power, pp. 325-331.

34. C.I. Grimm, "Construction Methods at Bonneville," Civil Engineering 6 (Oct. 1936), pp. 671-673; L.E. Kurtichanof, "Electrical Features of the Bonneville Project."

35. L.E. Kurtichanof, "Electrical Features of the Bonneville Project."

36. The turbine technology chosen for Bonneville is briefly described in C.C. Galbraith, "Kaplan Turbines for Bonneville," Engineering-News Record 118 (May 27, 1937), pp. 765-769. This article noted that "the necessity, then, of securing a high efficiency over the wide range of heads under which the plant

normally will operate, in addition to the government requirement of high capacity left no choice but an adjustable blade runner. Accordingly, the Kaplan type, with blade angle and gate openings automatically adjusted to the net head available, was selected." Future research into how, and why, American engineers finally became interested in adapting the Kaplan turbine would best look to the records of large turbine manufacturers (such as the S. Morgan Smith Co., suppliers of the Bonneville turbines) or electric generator manufacturers such as General Electric. No material exists in the Portland District records on this subject.

37. These engineering consultants included D.C. Henny, Louis C. Hill, John Hogan, L.F. Harza, F.H. Cothran, J.C. Stevens, and Raymond Davis.

38. For data on his career see, "David Christian Henny," Transactions of the American Society of Civil Engineers 100 (1935), pp. 1577-1580. All data on Henny is taken from this obituary; see also D.C. Henny, "Stability of Straight Concrete Dams," Transactions of the American Society of Civil Engineers 99 (1934), pp. 1041-1061.

39. J.C. Stevens, "Models Cut Costs and Speed Construction," Civil Engineering 6 (Oct. 1936), pp. 674-677.

40. Raymond E. Davis, "Cement and Concrete Investigations for Bonneville Dam," p. 1.

41. Ibid.

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